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# INVESTIGATION OF THE HUMAN RESPONSE TO UPPER TORSO RETRACTION WITH WEIGHTED HELMETS


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**General Dynamics**


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**Final Report**

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The purpose of this effort was to investigate human response to upper torso retraction with added helmet weight using the AFRL Body Positioning and Restraint Device (BPRD). The results indicated that since the measured center-of-gravity (CG) of the worst-case test helmet fell outside the current limits and no injuries were observed, it can be stated that the current mass property limits are valid for the torso retraction environment. In addition, since subjects met the current retraction time requirement with 2 pounds of added helmet weight, the torso retraction specification is valid for aircrew wearing helmet mounted systems (HMS).

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# PREFACE

This experimental effort was accomplished by the Applied Neuroscience Branch (formerly the Biomechanics Branch), Human Effectiveness Directorate of the Air Force Research Laboratory of the 711$^{th}$ Human Performance Wing at Wright-Patterson Air Force Base, Ohio. Approval for the use of human volunteers in this program was authorized by the Wright Research Site Institutional Review Board (IRB) at Wright Patterson AFB, Ohio under protocol 2001-0011. Technical support for the testing was provided by General Dynamics AIES under contract F41624-97-D-6004.

# 1.0 INTRODUCTION

Repositioning of aircrew against the seat back is essential prior to ejection. Laboratory data suggest that ejecting crewmembers would benefit from an inertia reel that can retract the torso in 150 milliseconds. The current inertia reel specification requires that haulback must be completed in fewer than 300 milliseconds [1,2]. This figure is based on canopy removal times rather than human tolerance to the inertia reel retraction forces and accelerations [3,6]. A recent laboratory study has shown that a volunteer panel representative of the expanded aircrew population can tolerate upper torso retraction in approximately 160-170 milliseconds [7]. Several other studies have been performed in the laboratory using human volunteers to demonstrate that haulback can be completed much quicker than 300 milliseconds without additional risk of injury to the occupant [4,5,6]. A U.S. Navy study showed that powered inertia reels could be ineffective in overcoming loads imposed on an out-of-position manikin during the onset of the catapult acceleration [8]. This condition is more likely with larger occupants and could increase neck flexion injury risk if added helmet weight is present. Most of the previous studies were performed using the standard flight helmet at the time of the study (HGU 26/P or 55/P).

The effects of added helmet weight on human response to vertical impact have been well documented. Studies by Perry using a weighted HGU-55/P helmet [9] and operational helmet mounted systems [10,11] have established criteria for safe human exposures in the vertical direction. However, the torso retraction event produces different dynamics and a unique injury risk. Manikin testing, data from previous retraction studies, and the established criteria from vertical impact studies must be investigated before establishing new or validating existing injury criteria.

Helmet Mounted Systems (HMS) are currently being used in ejection seat aircraft. There is a concern for crewmember safety during the ejection sequence while wearing HMS. The risk of neck injury during the catapult phase of ejection has been studied using human volunteers and manikins at Wright-Patterson Air Force Base (WPAFB) [9,10,11]. The upper torso retraction event, which is initiated prior to catapult ignition, can also impart significant forces and accelerations on ejecting crewmembers. No research has been conducted on the upper torso retraction event using HMS. A recent study performed at Air Force Research Laboratory (AFRL) by Pint and Buhrman documented significant response differences between males and females during rapid upper torso retraction [7]. Of particular concern during this study was the difference in resultant head accelerations measured between male and female volunteers. All tests were performed using the HGU-55/P helmet with standard chinstrap. Although the retraction speeds were much greater than those typically observed during operational ejections, it is believed that the neck loads and torques experienced during the study could be similar to those seen during operational ejections where HMS are being worn.

The purpose of this effort was to investigate the human response to upper torso retraction with added helmet weight. The data obtained from this investigation will show whether mass property limits currently imposed on HMS for the vertical impact environment are applicable to torso retraction. The data will also validate current performance criteria for powered inertia reels and provide baseline data for use in future development efforts such as fast-acting inertia reels or harness pre-tensioning devices.

## 2.0 METHODS

The AFRL Body Positioning and Restraint Device (BPRD) (Figure 1) was used to perform upper torso retraction on a panel of human volunteers and manikins. The BPRD is a hydraulically actuated retraction system designed to simulate the force-time history of a powered inertia reel [16]. All subjects wore a variable weight HGU-55/P flight helmet and either a PCU-15/P or PCU-16/P restraint harness for each test. A ½ inch strip of Confor™ C-47 padding was added to the back of the helmet for each test. The extra padding provided additional risk reduction in the event of a head strike against the headrest. A ½ inch layer of felt padding was also added to the metal headrest for the same purpose. Subjects were seated on an instrumented generic seat with a seatback reclined 13 degrees from vertical and a seat pan inclined 6 degrees from horizontal. A standard lap belt was used to restrain the subject in the seat during retraction. A custom shoulder strap assembly attached the subject's restraint harness to the retraction cable. The retraction cable was connected through a series of pulleys to a retraction piston. The adjustable retraction piston provided the pre-selected retraction speed and distance profiles. The subjects preloaded the restraint system by leaning into the harness with 20 ± 5 lb of opposing force and performing a straining maneuver prior to the retraction event. The opposing force value was measured with a load cell connecting the retraction cable and retraction piston and displayed to the subject and the facility safety officer on a computer monitor. After an audible countdown was complete, the subjects were retracted automatically.

Figure 1. Body Positioning and Restraint Device (BPRD)

The subjects were fastened to the retraction cable with the piston fully retracted and adjusted to a maximum of 25 lb harness strap tension. This assured that no significant after-load would be placed on the subject by the action of the hydraulic piston after retraction. In the operational cockpit the operational inertia reel generally does produce an after-load following retraction. By specification, this after-load is limited to 100 lb one minute after retraction is complete [17]. Since the goal of the study was to examine the retraction event, not the after-loading, the 25 lb limit was appropriate.

Prior to human subject testing, a risk assessment was performed. The method of risk assessment used for this study began with a review of the manikin and human subject data obtained from previous studies conducted at AFRL using the BPRD [7]. A computational model was developed to calculate the loads and torques produced in the cervical spine of human subjects. The model uses the mass properties of the subject's head and the measured angular and linear accelerations measured during the retraction exposure to calculate the loads and torques. Using these data, estimates of injury risk were obtained using the National Highway Traffic Safety Administration's (NHTSA) Neck Injury Criteria (Nij) computation [12]. Published neck injury criteria and limits were then reviewed for comparison purposes. The combination of the computed Nij values and calculated neck loads provided baseline risk data in preparation for human and manikin testing with weighted helmets.

After the risk assessment using data from previous studies was complete, a series of manikin tests was conducted using weighted helmets. A Lightest Occupant In Service (LOIS) weighing approximately 103 lb and an Advanced Dynamic Anthropomorphic Manikin (ADAM-L) weighing approximately 218 lb completed tests according to Table 1.

Table 1. Manikin Test Matrix

| Cell | Helmet | Hydraulic Pressure (psi) | Retraction Distance (inches) | Mask | Extra Helmet Weight (lb) |
|---|---|---|---|---|---|
| A | 55/P | 400 | 10 | - | - |
| B | 55/P | 400 | 14 | - | - |
| C | 55/P | 600 | 10 | - | - |
| D | 55/P | 600 | 14 | - | - |
| E | 55/P HALO | 400 | 10 | - | - |
| F | 55/P HALO | 400 | 14 | - | - |
| G | 55/P HALO | 600 | 10 | - | - |
| H | 55/P HALO | 600 | 14 | - | - |
| I | 55/P HALO | 400 | 10 | - | 0.5 |
| J | 55/P HALO | 400 | 14 | - | 0.5 |
| K | 55/P HALO | 600 | 10 | - | 0.5 |
| L | 55/P HALO | 600 | 14 | - | 0.5 |
| M | 55/P HALO | 400 | 10 | - | 1.0 |
| N | 55/P HALO | 400 | 14 | - | 1.0 |
| O | 55/P HALO | 600 | 10 | - | 1.0 |
| P | 55/P HALO | 600 | 14 | - | 1.0 |
| Q | 55/P HALO | 400 | 10 | - | 2.0 |
| R | 55/P HALO | 400 | 14 | - | 2.0 |
| S | 55/P HALO | 600 | 10 | - | 2.0 |
| T | 55/P HALO | 600 | 14 | - | 2.0 |
| BB | 55/P | 400 | 14 | 12/P | - |
| DD | 55/P | 600 | 14 | 12/P | - |
| FF | 55/P HALO | 400 | 14 | 12/P | - |
| HH | 55/P HALO | 600 | 14 | 12/P | - |
| JJ | 55/P HALO | 400 | 14 | 12/P | 0.5 |
| LL | 55/P HALO | 600 | 14 | 12/P | 0.5 |
| NN | 55/P HALO | 400 | 14 | 12/P | 1.0 |
| PP | 55/P HALO | 600 | 14 | 12/P | 1.0 |
| RR | 55/P HALO | 400 | 14 | 12/P | 2.0 |
| TT | 55/P HALO | 600 | 14 | 12/P | 2.0 |

Neck load calculations and Nij values for manikin tests with weighted helmets were compared to manikin and human data from previous retraction programs conducted using standard HGU-55/P helmets with no added weight. The comparison showed that testing at 600 psi facility hydraulic pressure with 2 lb of added helmet weight would yield a similar, yet conservative, injury risk to testing at 900 psi [7] with no added helmet weight (using the Nij criteria as the basis for comparison). A sample of one of the comparison plots for the LOIS manikin is shown in Figure 2.

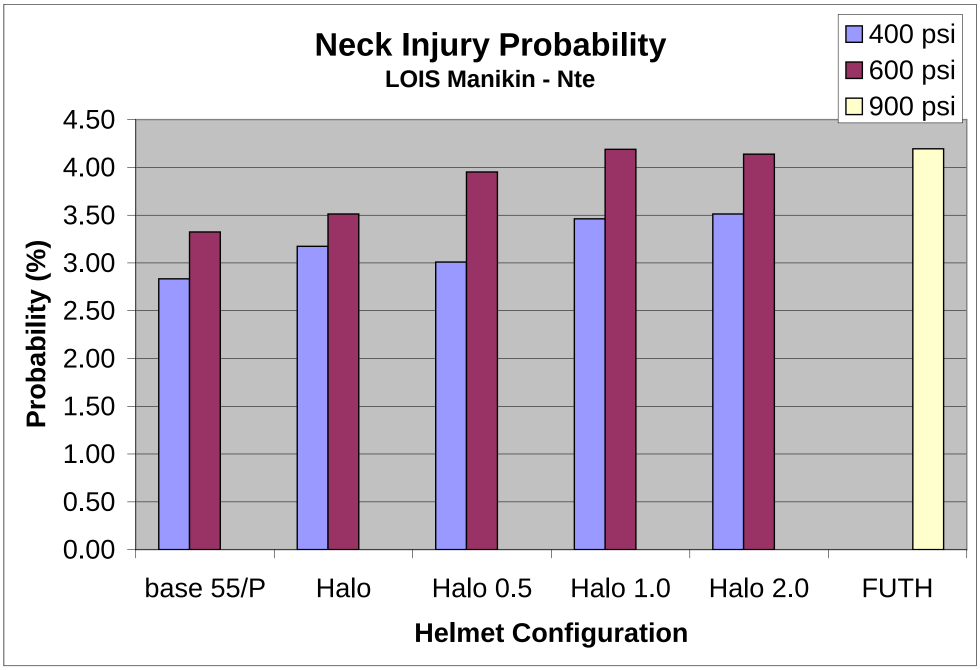


Figure 2. Sample Risk Assessment Plot

Similar plots were evaluated for the ADAM-L manikin. Based on the comparison of neck injury probability, a recommended test matrix for human subjects was presented to the Wright Site Institutional Review Board (IRB) for approval. The approved human test matrix is shown in Table 2.

Table 2. Human Test Matrix

| Cell | Helmet | Hydraulic Pressure (psi) | Retraction Distance (inches) | Mask | Extra Helmet Weight (lb) |
|---|---|---|---|---|---|
| FF# | 55/P HALO | 400 | 14 | 12/P | - |
| GG | 55/P HALO | 500 | 14 | 12/P | - |
| HH | 55/P HALO | 600 | 14 | 12/P | - |
| NN | 55/P HALO | 400 | 14 | 12/P | 1.0 |
| OO | 55/P HALO | 500 | 14 | 12/P | 1.0 |
| PP* | 55/P HALO | 600 | 14 | 12/P | 1.0 |
| RR | 55/P HALO | 400 | 14 | 12/P | 2.0 |
| SS | 55/P HALO | 500 | 14 | 12/P | 2.0 |
| TT* | 55/P HALO | 600 | 14 | 12/P | 2.0 |

Notes:
# - denotes training cell
* - denotes cells that will be completed by human subjects weighing over 140 lbs.

Based on the IRB review of previous data, it was recommended that only subjects weighing over 140 lb complete cells PP and TT. This decision was based more on the relative lack of small male exposure data from previous studies rather than the assessment of small-stature subject risk. Each subject completed the cells in Table 2 in the order listed. This procedure allowed the investigators to analyze the risk data (neck load and Nij data) prior to the subjects proceeding to subsequent cells where the exposures were more severe. The helmet configuration for cells RR, SS, and TT was chosen to approximate the mass properties of the worst-case HMS being flown by Air Force pilots at the time the study was planned [13].

The human subject panel consisted of 21 males and 9 females. Anthropometric range data for the panel are shown in Table 3.

Table 3. Human Subject Anthropometry

| | **Male (n=21)** | | | | | **Female (n=9)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **N** | **Mean** | **Std** | **Min** | **Max** | **N** | **Mean** | **Std** | **Min** | **Max** |
| Weight (lbs) | 21 | 182 | 37 | 127 | 261 | 9 | 139 | 28 | 116 | 205 |
| Sitting Height (in) | 21 | 36.3 | 1.0 | 35.0 | 38.3 | 9 | 34.4 | 1.3 | 32.8 | 36.7 |
| Neck Circumference (in) | 21 | 15.0 | 1.0 | 13.2 | 17.7 | 9 | 12.4 | 0.5 | 11.8 | 13.0 |

A variable weight HGU-55/P helmet (nominal weight of 2.98 lbs), designated 55/P HALO in the test matrix, with integrated chin/nape strap (ICNS) and zeta-liner insert were used for all human and manikin tests (Figure 3). The HALO helmet provided for adjustable mass properties. Weights were added and positioned to reflect the desired mass properties chosen by the investigators. Medium (M), large (L), and extra-large (XL) helmets were used according to each subject's head measurements. The weights added to the helmet were placed in the front-center position. The halo portion of the helmet was positioned in the full-front position on the M and L helmets and 1 inch aft on the XL helmet. A modified MBU-12/P oxygen mask was used for all human tests. A portion of the front of the mask was removed to accommodate the instrumented mouth pack. The mask was used to provide rotational stability to the helmet.

Figure 3. HALO Helmet with Modified Mask

The PCU-15/16/P harness with standard lap belt was used in each test.  Subjects wore cutoff long underwear and stockings for each test.  A human subject in the pre-retraction position is shown in Figure 4.


Figure 4.  Pre-Retraction Test Position

The BPRD facility was instrumented with load cells in the seat pan, upper seat back, headrest, and retraction piston.  A load cell was also placed between the retraction piston and the retraction cable to measure the load in the cable prior to and during retraction.  A linear accelerometer was also mounted on the retraction piston.  Manikin subjects were instrumented with neck load cells and triaxial and angular accelerometers in the head and chest.  Human subjects used an instrumented bite bar and an external chest pack to measure linear and angular acceleration in the respective areas.  Additional information describing the facility and instrumentation is provided in Appendix A.

# 3.0 RESULTS

## 3.1 Mass Property Limit Validation

According to HMS mass property limits developed experimentally by AFRL, the center of gravity (CG) shall fall within a volume around the ADAM-L head anatomical origin that ranges in the x-axis (fore-aft) from –0.8 to 0.5 in., in the y-axis from –0.15 to 0.15 in., and in the z-axis (vertical) from 0.5 to 1.5 in.  The CG calculation shall include the weights and CGs of the ADAM Head form, HGU-55/P Helmet, MBU-20/P Oxygen Mask (with 3 in. of hose), and the HMS [13].  These limits are assumed to be valid for HMS weighing 5 lb or less and are applicable for ACES II ejection seat applications [14].  Recent investigations have modified these limits to account for HMS weighing over 5 lb [13].  The modified limits were not established at the time this study was conducted.  The CG of the large HGU-55/P helmet with 2 lb of added helmet weight and modified MBU-12/P mask was measured to be 0.8 in. in the x-axis, 0.12 in. in the y-axis, and 1.42 in. in the z-axis (Figure 5).

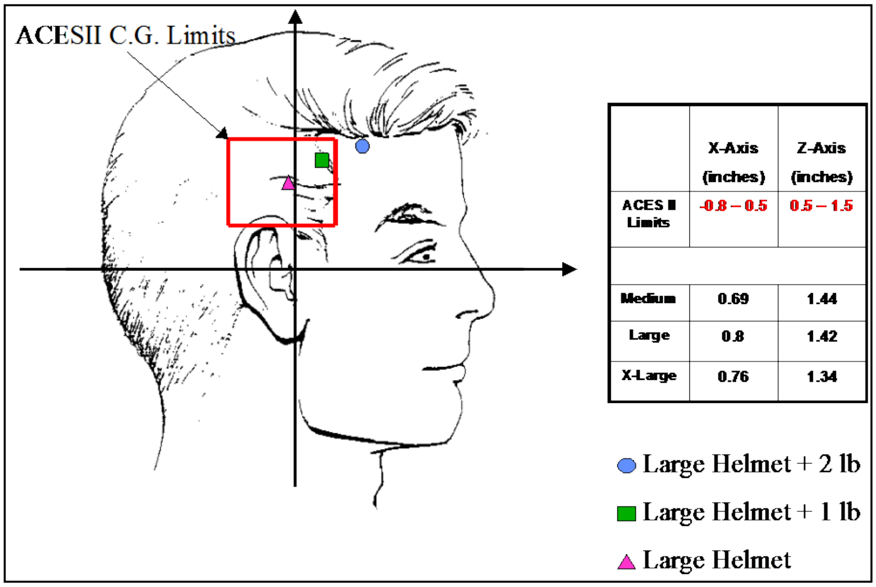


Figure 5. Mass Property Limit Validation

## 3.2 Retraction Time Validation

MIL-DTL-9479E states that torso retraction of up to 18 in. must be complete within 300 milliseconds of system initiation. Retraction tests were conducted at lengths up to 14 in. Operational reels generally provide up to 18 in. of strap length, but the maximum retraction length is approximately 14-15 in. [4]. For each helmet configuration (0, 1, and 2 lb of added helmet weight), the test panel was safely retracted from 14 in. in fewer than 300 milliseconds (Figure 6). The performance specification is therefore validated for aircrew wearing HMS.

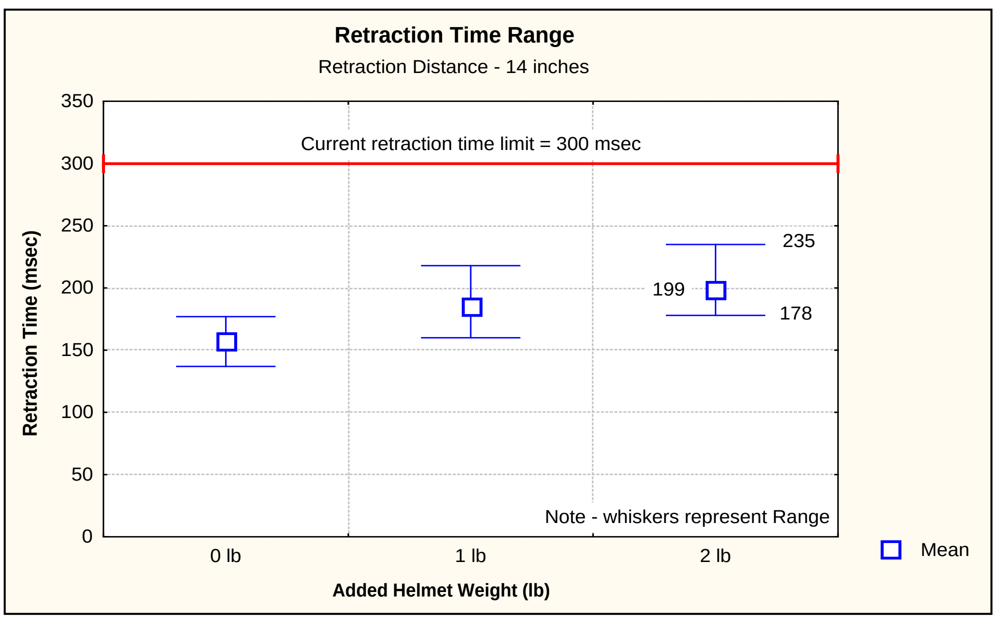


Figure 6. Retraction Time Validation

### 3.3 Subject Response Differences

One of the primary objectives of this study was to investigate the human response to upper torso retraction with added helmet weight. An analysis of selected subject response parameters showed several noteworthy trends. Based on the results of previous studies, the effect of gender, subject weight, sitting height, and neck circumference on selected response parameters was examined. The measured resultant head acceleration, and positive (flexion) and negative (extension) head angular acceleration were the chosen response parameters. These parameters were chosen because they provide the key inputs to neck injury risk calculations.

A two-tailed, 2-sample, t-test was used to compare the male and female response for each of the selected response parameters for each combination of helmet weight and retraction speed. A sample result of the t-test for 0 lb of added helmet weight is shown in Figure 7. The difference between the means for each gender is shown by percentage. The asterisk (*) denotes a significant difference ($p \leq 0.05$). A total of 24 cases were analyzed - 3 helmet weights, 3 retraction speeds, and 3 response parameters (Table 4). Cell TT data were not included in the analysis because no female subjects completed that cell. Significant differences ($p \leq 0.05$) between genders resulting from the t-test are shaded. In 10 of the 24 cases, a significant difference was observed.

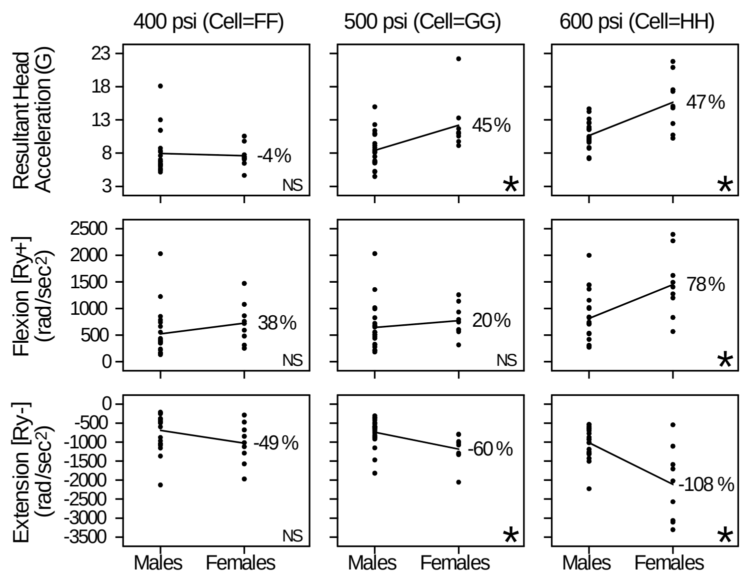


Figure 7. T-test Cases 1-9 (0 lb Added Helmet Weight)

Table 4. Gender Effects on Subject Response

| Dependent Variable | Cell | 2-tailed 2-sample t-test | | | | | | Analysis of Covariance | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | | Female | | Percent | | LS Means | | Percent | |
| | | N | Mean ( Std) | N | Mean ( Std) | Change | p-value | Male | Female | Change | p-value |
| Resultant Head Acceleration (G) | FF | 21 | 7.94 ( 3.16) | 9 | 7.60 ( 1.73) | -4.3 | 0.7659 | 9.69 | 3.51 | -63.8 | 0.0032 |
| | GG | 21 | 8.43 ( 2.57) | 9 | 12.19 ( 3.93) | 44.7 | 0.0041 | 10.15 | 8.16 | -19.6 | 0.3390 |
| | HH | 21 | 10.65 ( 2.15) | 9 | 15.64 ( 4.12) | 46.9 | 0.0064 | 12.30 | 11.78 | -4.3 | 0.7832 |
| | NN | 21 | 6.99 ( 1.48) | 8 | 8.19 ( 2.08) | 17.2 | 0.0918 | 7.28 | 7.44 | 2.3 | 0.8929 |
| | OO | 21 | 8.67 ( 2.36) | 8 | 12.23 ( 4.13) | 41.1 | 0.0478 | 10.42 | 7.64 | -26.7 | 0.1435 |
| | PP | 18 | 9.30 ( 1.61) | 3 | 10.05 ( 0.09) | 8.1 | 0.0665 | 9.54 | 8.59 | -10.0 | 0.5012 |
| | RR | 21 | 6.77 ( 1.66) | 7 | 8.49 ( 2.50) | 25.3 | 0.0478 | 7.74 | 5.59 | -27.8 | 0.0878 |
| | SS | 19 | 8.17 ( 1.91) | 5 | 9.38 ( 1.43) | 14.8 | 0.2020 | 8.73 | 7.24 | -17.1 | 0.2878 |
| | TT | 14 | 8.76 ( 1.84) | | | | | | | | |
| Flexion [Ry+] (rad/sec$^2$) | FF | 21 | 525 ± 441 | 9 | 726 ± 383 | 38.4 | 0.2441 | 723 | 262 | -63.7 | 0.1708 |
| | GG | 21 | 644 ± 435 | 9 | 773 ± 297 | 20.1 | 0.4252 | 846 | 300 | -64.5 | 0.0937 |
| | HH | 21 | 816 ± 459 | 9 | 1450 ± 597 | 77.7 | 0.0037 | 915 | 1221 | 33.4 | 0.4983 |
| | NN | 21 | 357 ± 313 | 8 | 764 ± 519 | 113.9 | 0.0151 | 308 | 893 | 190.0 | 0.0858 |
| | OO | 21 | 628 ± 386 | 7 | 765 ± 405 | 21.8 | 0.4288 | 890 | -21 | -102.3 | 0.0006 |
| | PP | 18 | 740 ± 400 | 3 | 772 ± 47 | 4.3 | 0.7507 | 797 | 431 | -45.9 | 0.3215 |
| | RR | 21 | 363 ± 226 | 7 | 394 ± 162 | 8.5 | 0.7411 | 451 | 131 | -70.8 | 0.0446 |
| | SS | 19 | 491 ± 241 | 5 | 548 ± 156 | 11.6 | 0.6243 | 567 | 258 | -54.5 | 0.1129 |
| | TT | 13 | 506 ± 174 | | | | | | | | |
| Extension [Ry-] (rad/sec$^2$) | FF | 21 | -689 ± 490 | 9 | -1028 ± 533 | 49.3 | 0.1011 | -853 | -646 | -24.2 | 0.5916 |
| | GG | 21 | -741 ± 368 | 9 | -1185 ± 385 | 59.9 | 0.0058 | -921 | -764 | -17.0 | 0.6010 |
| | HH | 21 | -1017 ( 416) | 9 | -2113 ( 963) | 107.9 | 0.0090 | -1171 | -1750 | 49.4 | 0.3020 |
| | NN | 20 | -423 ( 183) | 8 | -1082 ( 785) | 155.8 | 0.0496 | -569 | -718 | 26.3 | 0.7079 |
| | OO | 21 | -664 ( 316) | 8 | -1283 ( 809) | 93.2 | 0.0695 | -928 | -589 | -36.5 | 0.3301 |
| | PP | 18 | -800 ( 415) | 3 | -956 ( 360) | 19.4 | 0.5495 | -825 | -809 | -1.9 | 0.9726 |
| | RR | 19 | -387 ( 118) | 7 | -469 ( 162) | 21.2 | 0.1682 | -372 | -508 | 36.4 | 0.2834 |
| | SS | 18 | -504 ( 175) | 5 | -704 ( 222) | 39.6 | 0.0444 | -549 | -542 | -1.2 | 0.9668 |
| | TT | 13 | -714 ( 369) | | | | | | | | |

Responses by gender were compared using the t-test without consideration for subject anthropometry. It is possible that the response differences were a result of anthropometric differences rather than gender. To test this assertion, an analysis of covariance was used. In the analysis of covariance, genders were compared using the average weight, sitting height, and neck circumference of the entire panel using an equal slopes model. The equal slopes model adjusts for the size difference in the genders. After adjusting for size differences on the same 24 cases where the t-test was performed, only 3 of the 24 cases had significant differences between genders. This suggests that the differences observed from the t-test were mostly due to anthropometric considerations rather than gender. The results of the analysis of covariance are shown on the right side of Table 4. Significant differences ($p < 0.05$) between genders resulting from the analysis of covariance are shaded.

Once it was established that anthropometry had an effect on subject response, further analysis was undertaken to determine the effect of individual anthropometric variables on subject response. Simple linear regression (Pearson correlation) was performed using the same three response parameters as dependent variables regressed on subject weight, sitting height, and neck circumference for each gender. A sample result of the linear regression for neck circumference is shown in Figure 8.

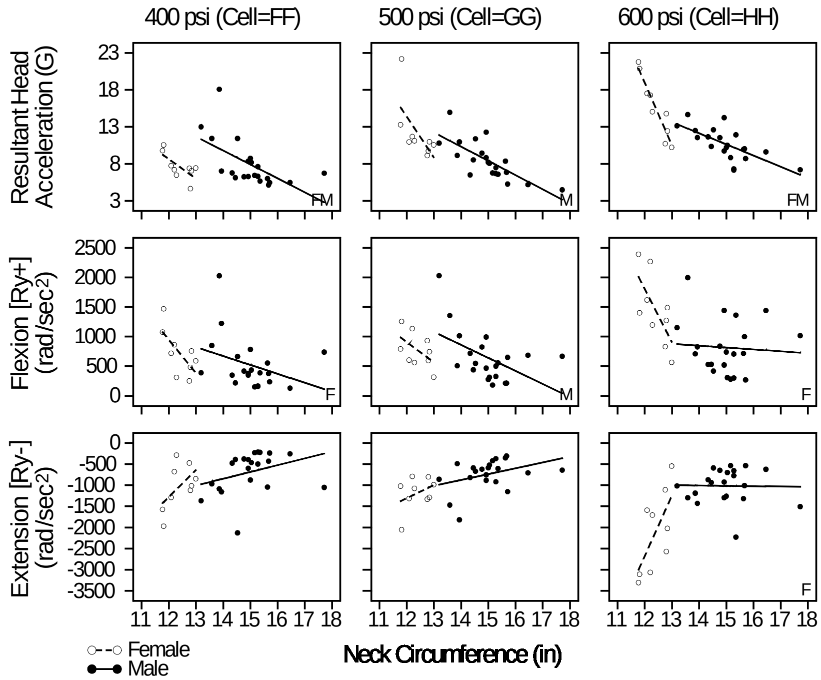


Figure 8. Linear Regression for Neck Circumference

The summary of the linear regression data for each anthropometric variable is shown in Table 5. Instances where the anthropometric variable had a significant effect ($p < 0.05$) on the subject response variable are shaded. An “F” or “M” in the lower right corner of each plot designates significance for the respective gender. Subject weight, sitting height, and neck circumference had a significant effect on the measured peak resultant head acceleration in 24 of 51 cases. Of these 24 significant cases, 21 of them were for males. The effect was not as profound for the measured positive (flexion) and negative (extension) angular head acceleration (12 of 51 and 7 of 51 significant effects respectively). As was the case in the gender analysis, female data were not analyzed for cell TT because no females completed this cell.

## Table 5. Anthropometric Factors and Subject Response

| Dependent Variable | Cell | Gender | N | Weight (lbs) | | | | Sitting Height (in) | | | | Neck Circumference (in) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Int | Slope | R2 | p | Int | Slope | R2 | p | Int | Slope | R2 | p |
| Resultant Head Acceleration (G) | FF | F | 9 | 10.16 | -0.019 | 0.08 | 0.4685 | 26.23 | -0.541 | 0.17 | 0.2700 | 40.27 | -2.637 | 0.50 | 0.0342 |
| | | M | 21 | 16.35 | -0.047 | 0.28 | 0.0146 | 70.58 | -1.723 | 0.29 | 0.0113 | 36.07 | -1.877 | 0.35 | 0.0047 |
| | GG | F | 9 | 19.76 | -0.054 | 0.14 | 0.3288 | 60.89 | -1.415 | 0.23 | 0.1958 | 80.95 | -5.548 | 0.43 | 0.0562 |
| | | M | 21 | 17.91 | -0.053 | 0.54 | 0.0001 | 55.81 | -1.304 | 0.25 | 0.0201 | 37.21 | -1.920 | 0.55 | 0.0001 |
| | HH | F | 9 | 28.46 | -0.092 | 0.38 | 0.0748 | 79.98 | -1.869 | 0.36 | 0.0888 | 120.25 | -8.441 | 0.90 | 0.0001 |
| | | M | 21 | 17.84 | -0.040 | 0.42 | 0.0015 | 49.48 | -1.068 | 0.24 | 0.0226 | 33.20 | -1.504 | 0.49 | 0.0004 |
| | NN | F | 8 | 11.50 | -0.023 | 0.13 | 0.3898 | 47.78 | -1.143 | 0.47 | 0.0613 | 32.54 | -1.959 | 0.20 | 0.2613 |
| | | M | 21 | 10.23 | -0.018 | 0.19 | 0.0474 | 29.17 | -0.610 | 0.17 | 0.0655 | 13.52 | -0.436 | 0.09 | 0.1968 |
| | OO | F | 8 | 18.67 | -0.046 | 0.12 | 0.3929 | 67.93 | -1.608 | 0.23 | 0.2243 | 89.83 | -6.242 | 0.52 | 0.0424 |
| | | M | 21 | 16.44 | -0.043 | 0.45 | 0.0008 | 57.08 | -1.332 | 0.31 | 0.0083 | 36.06 | -1.827 | 0.60 | 0.0001 |
| | PP | F | 3 | 9.95 | 0.001 | 0.04 | 0.8719 | 10.70 | -0.018 | 0.09 | 0.8109 | 2.35 | 0.599 | 0.68 | 0.3812 |
| | | M | 18 | 14.81 | -0.029 | 0.35 | 0.0093 | 29.84 | -0.563 | 0.13 | 0.1419 | 25.07 | -1.037 | 0.33 | 0.0130 |
| | RR | F | 7 | 10.77 | -0.017 | 0.04 | 0.6627 | 28.31 | -0.575 | 0.08 | 0.5341 | 47.00 | -3.110 | 0.38 | 0.1386 |
| | | M | 21 | 12.30 | -0.030 | 0.48 | 0.0005 | 42.12 | -0.972 | 0.34 | 0.0057 | 25.56 | -1.253 | 0.57 | 0.0001 |
| | SS | F | 5 | 5.30 | 0.031 | 0.08 | 0.6420 | -13.95 | 0.682 | 0.17 | 0.4885 | 26.89 | -1.410 | 0.22 | 0.4239 |
| | | M | 19 | 13.18 | -0.027 | 0.32 | 0.0117 | 29.68 | -0.591 | 0.10 | 0.1900 | 25.32 | -1.139 | 0.37 | 0.0057 |
| | TT | M | 14 | 14.79 | -0.030 | 0.32 | 0.0354 | 36.48 | -0.757 | 0.18 | 0.1259 | 25.14 | -1.060 | 0.23 | 0.0831 |
| Flexion [Ry+] (rad/sec2) | FF | F | 9 | 1191 | -3.36 | 0.05 | 0.5543 | 5075 | -126.3 | 0.19 | 0.2410 | 7711 | -563.6 | 0.46 | 0.0431 |
| | | M | 21 | 1192 | -3.73 | 0.09 | 0.1880 | 6834 | -173.6 | 0.15 | 0.0794 | 2779 | -150.4 | 0.12 | 0.1309 |
| | GG | F | 9 | 881 | -0.78 | 0.00 | 0.8583 | 140 | 18.4 | 0.01 | 0.8347 | 5020 | -342.7 | 0.29 | 0.1387 |
| | | M | 21 | 1640 | -5.54 | 0.21 | 0.0368 | 7311 | -183.4 | 0.18 | 0.0586 | 3939 | -219.9 | 0.25 | 0.0197 |
| | HH | F | 9 | 2163 | -5.10 | 0.06 | 0.5369 | 2974 | -44.3 | 0.01 | 0.8021 | 12611 | -900.6 | 0.49 | 0.0364 |
| | | M | 21 | 963 | -0.81 | 0.00 | 0.7911 | 999 | -5.0 | 0.00 | 0.9626 | 1289 | -31.5 | 0.00 | 0.7680 |
| | NN | F | 8 | 800 | -0.26 | 0.00 | 0.9705 | 1065 | -8.7 | 0.00 | 0.9609 | 848 | -6.7 | 0.00 | 0.9883 |
| | | M | 21 | 254 | 0.57 | 0.00 | 0.7762 | -7 | 10.0 | 0.00 | 0.8911 | -390 | 49.8 | 0.03 | 0.4911 |
| | OO | F | 7 | 714 | 0.35 | 0.00 | 0.9519 | -727 | 42.9 | 0.02 | 0.7751 | 9599 | -705.3 | 0.56 | 0.0527 |
| | | M | 21 | 1242 | -3.37 | 0.11 | 0.1488 | 7792 | -197.1 | 0.26 | 0.0187 | 4100 | -231.7 | 0.36 | 0.0041 |
| | PP | F | 3 | 515 | 1.49 | 0.99 | 0.0678 | -211 | 27.7 | 0.68 | 0.3850 | 2220 | -112.6 | 0.08 | 0.8147 |
| | | M | 18 | 830 | -0.47 | 0.00 | 0.8776 | 8115 | -202.3 | 0.27 | 0.0267 | 1867 | -74.2 | 0.03 | 0.5135 |
| | RR | F | 7 | 804 | -2.99 | 0.32 | 0.1886 | 1563 | -33.9 | 0.07 | 0.5723 | 3506 | -251.2 | 0.60 | 0.0416 |
| | | M | 21 | 894 | -2.90 | 0.24 | 0.0241 | 4193 | -105.4 | 0.21 | 0.0343 | 2245 | -125.6 | 0.31 | 0.0091 |
| | SS | F | 5 | 857 | -2.38 | 0.04 | 0.7505 | 589 | -1.2 | 0.00 | 0.9914 | 3097 | -205.3 | 0.39 | 0.2596 |
| | | M | 19 | 848 | -1.92 | 0.10 | 0.1836 | 3389 | -79.7 | 0.11 | 0.1602 | 2120 | -108.2 | 0.21 | 0.0488 |
| | TT | M | 13 | 558 | -0.26 | 0.00 | 0.8690 | 10 | 13.5 | 0.01 | 0.8033 | 999 | -31.8 | 0.02 | 0.6265 |
| Extension [Ry-] (rad/sec$^2$) | FF | F | 9 | -1731 | 5.08 | 0.06 | 0.5195 | -9502 | 246.2 | 0.37 | 0.0810 | -8963 | 640.3 | 0.31 | 0.1197 |
| | | M | 21 | -1737 | 5.86 | 0.18 | 0.0563 | -8247 | 207.9 | 0.18 | 0.0568 | -3086 | 159.9 | 0.11 | 0.1495 |
| | GG | F | 9 | -1262 | 0.55 | 0.00 | 0.9219 | -3849 | 77.4 | 0.07 | 0.4895 | -5027 | 310.1 | 0.14 | 0.3225 |
| | | M | 21 | -1396 | 3.64 | 0.13 | 0.1140 | -7741 | 192.6 | 0.27 | 0.0158 | -2806 | 137.8 | 0.14 | 0.0957 |
| | HH | F | 9 | -3779 | 11.91 | 0.12 | 0.3631 | -6613 | 130.8 | 0.03 | 0.6447 | -19845 | 1430.9 | 0.47 | 0.0407 |
| | | M | 21 | -641 | -2.08 | 0.03 | 0.4505 | 1258 | -62.6 | 0.02 | 0.5183 | -897 | -8.0 | 0.00 | 0.9346 |
| | NN | F | 8 | -1483 | 2.85 | 0.01 | 0.7882 | -7867 | 195.9 | 0.10 | 0.4541 | -4719 | 292.6 | 0.03 | 0.6721 |
| | | M | 20 | -1009 | 3.31 | 0.35 | 0.0065 | -3795 | 92.9 | 0.25 | 0.0259 | -2867 | 164.5 | 0.52 | 0.0004 |
| | OO | F | 8 | -2416 | 8.06 | 0.10 | 0.4455 | -14337 | 377.0 | 0.34 | 0.1323 | -16776 | 1246.3 | 0.54 | 0.0365 |
| | | M | 21 | -635 | -0.16 | 0.00 | 0.9353 | -4470 | 104.7 | 0.11 | 0.1446 | -1948 | 85.6 | 0.07 | 0.2355 |
| | PP | F | 3 | -2884 | 11.18 | 0.96 | 0.1236 | -7962 | 197.4 | 0.59 | 0.4408 | 6814 | -604.1 | 0.04 | 0.8705 |
| | | M | 18 | -780 | -0.11 | 0.00 | 0.9730 | -3572 | 76.0 | 0.04 | 0.4532 | -1616 | 53.6 | 0.01 | 0.6497 |
| | RR | F | 7 | -773 | 2.22 | 0.18 | 0.3498 | -2009 | 44.7 | 0.12 | 0.4497 | -3266 | 225.9 | 0.48 | 0.0823 |
| | | M | 19 | -385 | -0.01 | 0.00 | 0.9925 | -690 | 8.3 | 0.00 | 0.7770 | 68 | -30.0 | 0.05 | 0.3368 |
| | SS | F | 5 | -471 | -1.79 | 0.01 | 0.8671 | 1845 | -74.6 | 0.08 | 0.6356 | -4327 | 291.8 | 0.39 | 0.2597 |
| | | M | 18 | -933 | 2.34 | 0.28 | 0.0244 | -3097 | 71.2 | 0.18 | 0.0805 | -1679 | 78.2 | 0.21 | 0.0528 |
| | TT | M | 13 | -1791 | 5.31 | 0.25 | 0.0837 | -2346 | 44.4 | 0.01 | 0.6980 | -2649 | 124.8 | 0.08 | 0.3596 |

## 4.0 DISCUSSION

Anthropometric differences had a significant effect on selected subject response parameters with the effects on male subjects being more common. One of the limitations of the study was the small number of females who completed the higher helmet weight, faster retraction speed cells. Another was the anthropometric makeup of the panel itself. The female subjects were skewed toward the small end in stature and there were not corresponding male and female subjects for equivalent anthropometry.

Regardless of the limitations, the results show several interesting trends that may benefit from further analysis or research. First, the measured resultant head acceleration decreased with added helmet weight. In other words, it appears that the added helmet weight actually stabilized the head more than if there was no added weight. This trend was observed in both male and female subjects. One factor that could contribute to this trend is the increased level of familiarity with the exposure. In other words, the subjects got better at resisting head motion the more tests they completed. It is also possible that the small (n=5) number of females who completed the heaviest helmet cells were the best of the 9 who started the study. Second, the strong correlation between anthropometric effects on the measured resultant acceleration, but not on the angular acceleration, raises some doubt as to the reliability of the angular acceleration data. Early in the study, several sharp peaks were observed in the angular acceleration channels. Analysis of the video data showed no compelling evidence of such spikes. It is believed that the mouthpack instrumentation made contact with the cutout MBU-12/P mask during initial motion and/or during impact of the subject with the seatback. Confor™ padding was placed between the mouthpack and the mask early in the study in an effort to eliminate the spikes.

Based on the analysis of the anthropometric effects on resultant head acceleration, a risk profile can be established for the torso retraction environment with added helmet weight. The data show that subjects who are slight in stature (lower body weight), have short sitting height, and have small neck circumference tended to have significantly higher resultant head acceleration.

## 5.0 CONCLUSIONS

Because the measured CG of the worst-case test helmet fell outside the current limits, and no injuries were observed, it can be stated that the current mass property limits are valid for the torso retraction environment. Similarly, because all subjects met the current retraction time requirement with 2 lbs of added helmet weight, the torso retraction specification is valid for aircrew wearing HMS. The differences in subject response to torso retraction with added helmet weight appear to be mostly due to anthropometric rather than gender differences. Further research should be conducted to explore the effects of other anthropometric measurements on the subject response during impact and acceleration, including the sustained acceleration environment.

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# APPENDIX A – TEST FACILITY AND INSTRUMENTATION DESCRIPTION

GENERAL DYNAMICS
Advanced Information Systems

# TEST CONFIGURATION AND DATA ACQUISITION SYSTEM FOR UPPER TORSO RETRACTION WITH WEIGHTED HELMET

WHUTR STUDY

Study Number 200101

Prepared under Contract F41624-97-D-6004
CDRL A005

AUGUST 2003

General Dynamics
Advanced Information Systems
5200 Springfield Pike, Suite 200
Dayton, OH 45431

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## Introduction

General Dynamics Advanced Information Systems (GDAIS) prepared this report for the Air Force Research Laboratory, Human Effectiveness Directorate, Biodynamics and Acceleration Branch under Air Force contract F41624-97-D-6004. It describes the test facility, test configurations, data acquisition and analysis, and instrumentation procedures used for the Upper Torso Retraction with Weighted Helmet (WHUTR) Study (Study 200101) A series of impact tests were performed on the Body Positioning and Restraint Device (BPRD) located in Bldg 824 at Wright-Patterson AFB. An Advanced Dynamic Anthropomorphic Manikin (ADAM-L) weighing 218 lb, a Lightest Occupant in Service (LOIS) manikin weighing 103 lb, and human subjects were used in this test program. A total of 408 human and manikin tests were conducted between 18 June 01 and 11 Sep 02.

## Test Facility

### Body Positioning and Restraint Device

The Body Positioning and Restraining Device (BPRD) was developed at Wright-Patterson AFB for biomechanical testing. It simulates the sequence timing and cockpit interfaces of modern aircrew escape systems. It was designed to study the performance limits of automatic restraint and body positioning systems.

The BPRD is a hydraulically activated, cable-rigged system. It can simulate the positioning of various body segments individually or in any combination. Beta Industries designed the device based on a study they conducted and reported in AMRL-TR-71-101, "An Investigation of Automatic Restraint and Body Positioning Techniques". The facility frame and simulated seat were manufactured by the Air Force at Wright-Patterson AFB. The hydraulic power supply, valves, and actuators were purchased from the Pabco Fluid Power Company. DynCorp designed and implemented the system controls and interfaces to the laboratory data collection systems. The BPRD has been modified somewhat since its original manufacture. The current configuration is shown in Figure A-1.

The height of the simulated seat may be varied up to 2.5 inches. The device is instrumented such that during a subject retraction, the loads in the seat pan, lower back, upper back, and headrest may be measured independently. For the tests conducted in the WHUTR study, the lower back of the seat back was not instrumented. The Principal Investigator decided it was not necessary based on the results of the Fast Upper Torso Haulback (FUTH) study. A booster seat and footrest were used for subjects with small stature to maintain position consistency for all subjects. Other program documentation information is found in Table A-1.

### Test Fixture

All tests were conducted on the BPRD. The seat was centered on the support frame. A single, center mounted, hydraulic cylinder was used for retraction force and distance. Two pulley sets were used to direct the retraction cables through the back of the seat for subject retraction (Figure A-2). Each cable was attached to a shoulder strap with adjustable harness fittings that connected to the subject parachute harness.

**Figure A-1. BPRD Facility**

**Table A-1. Program Documentation Information**

| Equipment | ID |
|---|---|
| Facility | BPRD |
| Pin Number | N/A |
| Seat Fixture | BPRD |
| Seat Cushion | None |
| Harness | PCU-15 or16/P |
| Helmet | HGU-55/P (2.062 lbs) with HALO and Integrated Chin/Nape Strap<br>Added weight of 0,1, and 2 lbs |
| Inertia Reel | None |
| Lap Belt | ACES II |
| Oxygen Mask | Hollowed MBU-12/P |
| NVG/HMD | None |
| Neg-G Strap | None |
| Headrest Position | Vertical |
| Seat Pan Position | 9° above Horizontal |
| Seat Back Position | 13° aft of Vertical |

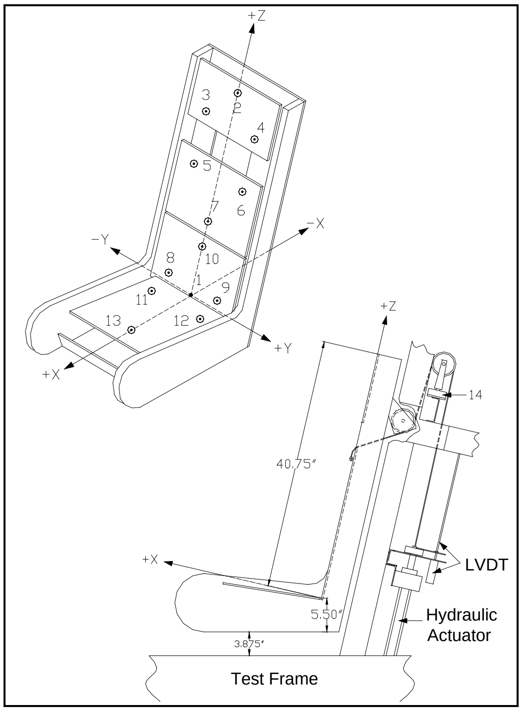



**Figure A-2. Cable Routing & Coordinate System**

The subjects were secured into the seat with the piston rod fully retracted. With the subject positioned against the seat back, the shoulder straps were tightened with 20 ± 5 lbs of tension. Then the piston was extended to the desired retraction distance per the test cell parameters. The subject was instructed to lean into the harness to take up all slack in the cable, and hold 20 ± 5 lbs of force in the cable. The cable force was displayed on a computer monitor in front of the subject for holding the pre-test tension. Figure A-3 shows a subject in the pre-test position.


**Figure A-3. Subject in Pre-Test Position**

## Test Matrix

Manikin tests were conducted at the conditions shown in the Manikin Test Matrix (Table A-2). Human tests were conducted at the conditions shown in the Human Test Matrix (Table A-3). Human subjects weighing 140 lbs or less were excluded by the Wright Site Institutional Review Board (WS IRB) from completing cells PP and TT.

**Table A-2. Manikin Test Matrix**

| Cell | Helmet | Hydraulic Pressure | Retraction Distance | Mask | Extra Helmet Weight (lb) |
|---|---|---|---|---|---|
| A | 55/P | 400 | 10 | - | - |
| B | 55/P | 400 | 14 | - | - |
| C | 55/P | 600 | 10 | - | - |
| D | 55/P | 600 | 14 | - | - |
| E | 55/P HALO | 400 | 10 | - | - |
| F | 55/P HALO | 400 | 14 | - | - |
| G | 55/P HALO | 600 | 10 | - | - |
| H | 55/P HALO | 600 | 14 | - | - |
| I | 55/P HALO | 400 | 10 | - | 0.5 |
| J | 55/P HALO | 400 | 14 | - | 0.5 |
| K | 55/P HALO | 600 | 10 | - | 0.5 |

| | | | | | |
|---|---|---|---|---|---|
| L | 55/P HALO | 600 | 14 | - | 0.5 |
| M | 55/P HALO | 400 | 10 | - | 1.0 |
| N | 55/P HALO | 400 | 14 | - | 1.0 |
| O | 55/P HALO | 600 | 10 | - | 1.0 |
| P | 55/P HALO | 600 | 14 | - | 1.0 |
| Q | 55/P HALO | 400 | 10 | - | 2.0 |
| R | 55/P HALO | 400 | 14 | - | 2.0 |
| S | 55/P HALO | 600 | 10 | - | 2.0 |
| T | 55/P HALO | 600 | 14 | - | 2.0 |
| BB | 55/P | 400 | 14 | 12/P | - |
| DD | 55/P | 600 | 14 | 12/P | - |
| FF | 55/P HALO | 400 | 14 | 12/P | - |
| HH | 55/P HALO | 600 | 14 | 12/P | - |
| JJ | 55/P HALO | 400 | 14 | 12/P | 0.5 |
| LL | 55/P HALO | 600 | 14 | 12/P | 0.5 |
| NN | 55/P HALO | 400 | 14 | 12/P | 1.0 |
| PP | 55/P HALO | 600 | 14 | 12/P | 1.0 |
| RR | 55/P HALO | 400 | 14 | 12/P | 2.0 |
| TT | 55/P HALO | 600 | 14 | 12/P | 2.0 |

**Table A-3. Human Test Matrix**

| Cell | Helmet | Hydraulic Pressure | Retraction Distance | Mask | Extra Helmet Weight (lb) |
|---|---|---|---|---|---|
| FF# | 55/P HALO | 400 | 14 | 12/P | - |
| GG | 55/P HALO | 500 | 14 | 12/P | - |
| HH | 55/P HALO | 600 | 14 | 12/P | - |
| NN | 55/P HALO | 400 | 14 | 12/P | 1.0 |
| OO | 55/P HALO | 500 | 14 | 12/P | 1.0 |
| PP* | 55/P HALO | 600 | 14 | 12/P | 1.0 |
| RR | 55/P HALO | 400 | 14 | 12/P | 2.0 |
| SS | 55/P HALO | 500 | 14 | 12/P | 2.0 |
| TT* | 55/P HALO | 600 | 14 | 12/P | 2.0 |

# - denotes training cell
* - denotes cells that were completed only by human subjects weighing over 140 lbs.

## Instrumentation

Accelerometers and load transducers were chosen to provide the optimum resolution over the expected test load range. Full-scale data ranges were chosen to provide the expected full-scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for optimum output prior to the start of the program. The accelerometers were adjusted for the effect of gravity using computer processing software. The component of a one G vector in line with the force of gravity that lies along the accelerometer axis was added to each accelerometer.

The origin of the seat coordinate system is designated as the seat reference point (SRP). The SRP is at the midpoint of the line segment formed by the intersection of the seat pan and seat back. All vector components (for accelerations, forces, moments, etc.) were positive when the vector component (X, Y and Z) was in the direction of the positive axis.

The laboratory uses two coordinate systems for the BPRD. One is referenced to the device carriage (termed BPRD coordinates). The BPRD seat back is reclined thirteen degrees (13° CW from Earth Zenith). The seat pan is angled up nine degrees (9° CW from Earth Horizontal). The BPRD coordinate system is established by the seat back. Positive Z is set parallel to the seat back. Positive X is in the eyes forward direction. The Y-axis is positive to the left according to the right hand rule. Reported data values labeled seat or back are referenced to the BPRD. The second coordinate system is for sensors located on the subject. It is referred to as the subject or manikin coordinate system. It also uses the right-handed convention. Positive X is along eyes forward, positive Z is up through the top of the head, and Y is positive through the left ear. The subject references move with the subject during the retraction sequence on this device. Data values labeled head or chest, for instance, are referenced to the subject coordinate system. A diagram of the seat coordinate system with a seat sketch and seat-mounted sensor locations is shown in Figure A-2.

The sensors used in this study are listed in the Program Set-Up and Calibration Log at the end of this report. The Program Set-Up and Calibration Log also provides channel assignments and sensor sensitivities.

The linear accelerometers were wired to provide a positive output voltage when the acceleration experienced by the accelerometer was applied in the +X, +Y and +Z directions. The angular accelerometers were wired to provide positive output voltage when the acceleration experienced by the accelerometer was in the direction of flexion. The load cells were wired to provide a positive output voltage when the force exerted by the load cell on the subject was applied in the +X, +Y or +Z direction.

The locations of the various load cells are shown in Figure A-2. The locations of each sensor relative to the SRP are shown in Table A-4.

Manikin head acceleration was measured using three linear accelerometers and one angular accelerometer mounted inside the manikin skull. Human subject head acceleration was measured using three linear accelerometers and one angular accelerometer mounted on a mouth pack and held in place by the bite-down force of the subject.

Manikin chest acceleration was measured using three linear accelerometers and one angular accelerometer mounted inside the manikin chest. Human subject chest acceleration was measured using three linear accelerometers and one angular accelerometer mounted in a chest box and held in place by using a velcro strap placed around the subject's chest (Figure A-4)

**Figure A-4.  Mouth and Chest Pack Instrumentation**

Left, right and center seat pan and back plate forces were measured using three Strainsert load cells per body segment plate.  Each group of three load cell values was summed to arrive at a body segment force magnitude.  A Strainsert load cell mounted to a pulley in the cable retraction system measured the shoulder strap forces (location fourteen in Figure A-2).

A Temposonics model Linear Displacement Transducer (LDT) was used to set the initial extension of the piston rod.  The LDT output was displayed to the BPRD operator on a voltmeter for setting up each test.  The LDT was used only to establish initial conditions.  No LDT output was recorded during testing.

**Table A-4. Sensor Locations**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WHUTR Study Verified on 22-Mar-2001 | | | | | | | |
| Transducer and Selspot Measurements 5-May-1999 Futh Study also used for WHUTR Study | | | | | | | |
| | | Measured | | | | Calculated | |
| Description | X (mm) | Y (mm) | Z (mm) | | X (mm) | Y (mm) | Z (mm) |
| Origin | 6.00 | 123.90 | -65.90 | | 0.00 | 0.00 | 0.00 |
| Center Headrest | 0.40 | 122.30 | 879.40 | | -5.60 | -1.60 | 945.30 |
| Right Headrest | 0.00 | 37.30 | 704.40 | | -6.00 | -86.60 | 770.30 |
| Left Headrest | -0.20 | 210.70 | 704.60 | | -6.20 | 86.80 | 770.50 |
| Right Upper Back Plate | 1.70 | -6.60 | 464.90 | | -4.30 | -130.50 | 530.80 |
| Left Upper Back Plate | 0.10 | 259.60 | 465.20 | | -5.90 | 135.70 | 531.10 |
| Center Upper Back Plate | 0.10 | 126.40 | 199.00 | | -5.90 | 2.50 | 353.90 |
| Right Lower Back Plate | 2.80 | -5.10 | -1.10 | | -3.20 | -129.00 | 64.80 |
| Left Lower Back Plate | 0.10 | 258.90 | -1.10 | | -5.90 | 135.00 | 64.80 |
| Center Lower Back Plate | 0.10 | 126.40 | 199.00 | | -5.90 | 2.50 | 264.90 |
| Right Top LED | 31.80 | -32.80 | 1147.40 | | -81.80 | -228.40 | 1203.80 |
| Upper Seat Back LED | -39.40 | 414.80 | 865.50 | | -45.40 | 290.90 | 931.40 |
| Lower Seat Back LED | -39.10 | 411.00 | 106.00 | | -45.10 | 287.10 | 171.90 |
| Aft Seat Pan LED | 221.80 | 404.00 | -72.60 | | 215.80 | 280.10 | -6.70 |
| Fore Seat Pan LED | 448.80 | 409.00 | -95.70 | | 442.80 | 285.10 | -29.80 |
| | | | | | | | |
| The z axis is parallel to the seat back of the BPRD. | | | | | | | |
| The X axis is eyes forward from the head. The Z axis is vertical. | | | | | | | |
| The Y axis is given by the right hand rule. | | | | | | | |
| | | | | | | | |
| Measurements for the load cells are taken at the contact point. | | | | | | | |
| The contact point is the point on the load cell where the external | | | | | | | |
| force is applied. | | | | | | | |
| The measurements for the load cells which anchor the harness | | | | | | | |
| were taken at the point where the harness is attached to the | | | | | | | |
| load cell. | | | | | | | |
| The SRP is the midpoint of the intersection of the seat back | | | | | | | |
| and seat pan. | | | | | | | |

## Transducer Calibration

Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the transducers. Pre-program and post-program calibrations are given in the Program Setup and Calibration Log. AFRL/HEPA verified all Strainsert load cells used in the test program.

The comparison method (Ensor, 1970) was used to calibrate the laboratory accelerometers. A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. A random noise generator drove the shaker table and the accelerometer output was collected. The frequency response and phase shift of the test accelerometer were determined by using Fourier analysis on a PC. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 20 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

GDAIS calibrated the cable force and seat mounted load cells and load links. These transducers were calibrated to a laboratory standard load cell in a special test fixture. The sensitivity and linearity of each test load cell were obtained by comparing the output of the test load cell to the output of the laboratory standard under identical loading conditions. Strainsert calibrates the laboratory standard load cell on a yearly basis.

The angular accelerometers are calibrated on a pre- and post-study basis by comparing their output to the output of a linear standard accelerometer. The angular sensors are mounted parallel to the axis of rotation of a Honeywell low inertia DC motor. The linear sensor is mounted perpendicular to the axis of rotation. An alternating current is supplied to the motor, which drives a constant sinusoidal angular acceleration of 100 Hz. The sensitivity of the angular accelerometer is calculated from the RMS output voltage to match the angular value computed from the linear standard.

## Data Acquisition

### Sensor Data

The EME DAS24 Data Acquisition and Storage System was used for all tests (Figure A-5). The DAS24 is provided signal conditioning and a recording system for transducers and events. The system is powered by an external 19 Volt DC power supply and communicates with the host computer through an RS422 interface.

**Figure A-5. Data Acquisition System**

The DAS24 accommodates up to 24 transducer channels and 16 events. The signal conditioning front end excites, amplifies and offsets transducer input signals to appropriate levels for analog to digital conversion. Transducer signals are amplified, filtered, digitized and recorded in the 4 Mbyte of onboard solid-state memory. All data were collected at 1000 samples per second and filtered at a 120 Hz cutoff frequency using an 8-pole Butterworth filter.

The C program ADASEME on a desktop PC configured the DAS24 prior to the start of the test, transferred test data from the DAS24 when the test was completed, and stored the collected test data in a binary data file. The program communicated with the DAS24 system by sending instructions over the RS422 interface.

Test data was reviewed after it was converted to digital format using the MS Excel processing program named WHUTRBpr.xls (see Data Processing section). The processing program produced a plot of the data stored for each channel as a function of time. The routine determined the minimum and maximum values of each data plot, calculated the rise time, pulse duration, and carriage acceleration, and created a disk file containing significant test parameters.

The Master Instrumentation Control Unit in the Instrumentation Station controlled data acquisition. Using a comparator, a test was initiated when the countdown clock reached zero. The comparator was set to start data collection at a pre-selected time.

Prior to placing a subject in the seat, data were recorded to establish a zero reference for all transducers. The reference data were stored separately from the test data and were used in the processing of the test data. A reference mark pulse was generated to mark the electronic data at a pre-selected time after test initiation to place the reference mark close to the impact point. The reference mark time was used as the start time for data processing of the electronic data.

## Selspot Motion Analysis System

The Selspot Motion Analysis System utilizes photosensitive cameras to track the motion of infrared LED targets attached to different points on the test fixture. The three-dimensional motion of the LEDs was determined by combining the images from two different Selspot cameras.

For this study, two Selspot cameras were mounted onboard the BPRD. They were mounted with a left oblique camera and a left side-view camera. Both cameras used 24 mm lenses.

The Selspot System includes a video monitor, a desktop PC, a HW VCU-2 VME Control Unit II, and a camera interface module (MCIM). The Selspot data collection and processing are performed by the Selspot MULTILAB System software. The Selspot test data was transferred over the network to an optical disk drive for permanent storage.

The Selspot System was calibrated by determining the camera locations and orientations prior to the start of the test program. The camera locations and orientations were referenced to the coordinate system of the Position Reference Structure (PRS). The PRS is shaped as a tetrahedron with reference LEDs 1, 2, 3 and 4 located at the vertices. The PRS is shown in Figure A-6.

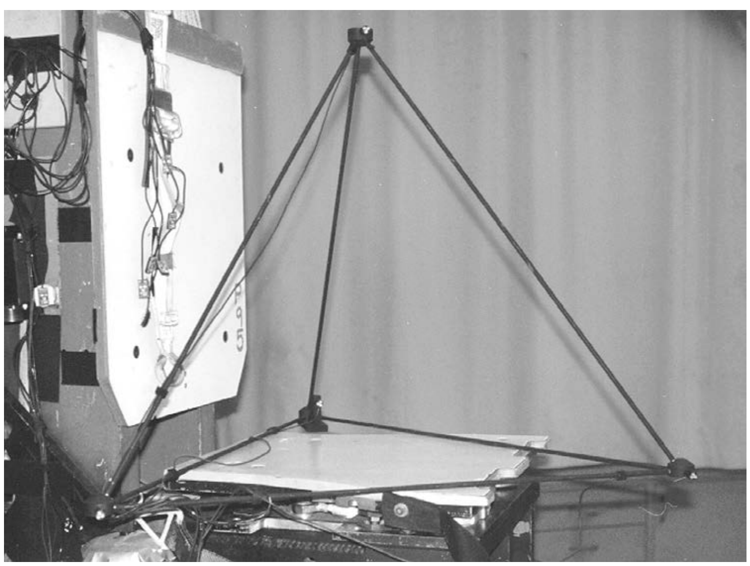


**Figure A-6. Position Reference Structure**

For all axes of the test, the motion of the subjects' helmet top, mouth, left shoulder, left ear, and chest (Table A-5) was quantified by tracking the motion of six subject-mounted LEDs. Four reference LEDs were placed on the test fixture. Figure A-7 identifies the subject-mounted LED target locations.

**Table A-5. LED Target Location**

| LED Target | Location |
|---|---|
| 1 | Top of Head |
| 2 | Mouth |
| 3 | Left Ear |
| 4 | Left Shoulder |
| 5 | Chest |

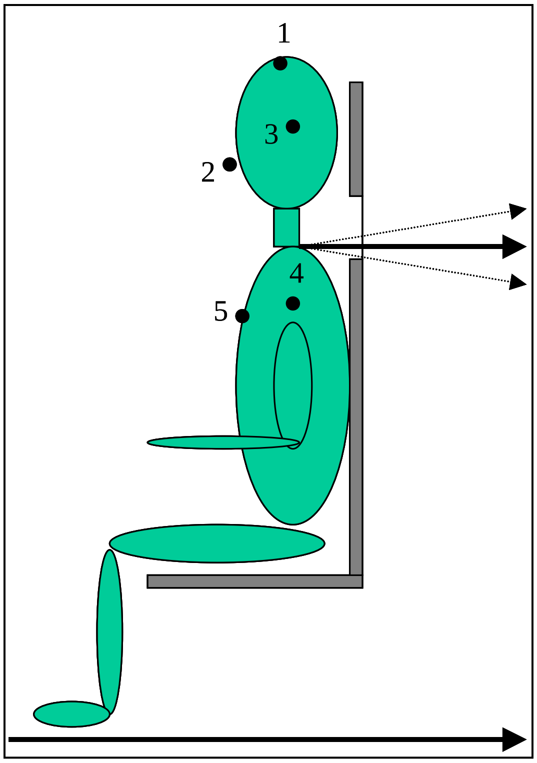



**Figure A-7. LED Target Location**

## Kodak High-Speed Video

A Kodak Ektapro 1000 video system was used to provide video coverage of each test. The Kodak system is capable of recording high-speed motion up to a rate of 1000 frames per second. For this study, the video was set to record at 500 frames per second. Immediate replay of the impact is possible at frame rates selected by the user.

The video files were downloaded and converted to AVI format, and placed in the HEPA Biodynamic Data Bank.

## Data Processing

The Excel 2000 Workbook WhutrBpr.xls was used to analyze the EME DAS test data from the WHUTR Study (BPRD Facility). WhutrBpr.xls contains the Visual Basic module Module1 and the forms UserForm1 and UserForm2. Module1 contains one main subroutine that calls numerous other subroutines and functions. WhutrBpr.xls calls the DLL functions in the Dynamic Link Libraries Scandll and Mathdll. The shortcut ctrl+r can be used to execute the Visual Basic module. The Visual Basic module displays the two user forms.

UserForm1 requests the user to enter the system acronym, study description, impact channel number, magnitude of the impact start level, start time, processing time, T0 bit number and reference mark bit number. The user has the option to find the Kodak start time, start at the reference mark time, and use the processing time as the impact window time. The user has the option to plot the channels, print out the summary sheet, print out the plots, create a test summary file for the Biodynamic Data Bank, and create a time history file for the Biodynamic Data Bank. Default values are displayed based on the last test that was analyzed. The default values are stored in worksheet "Defaults" inside the workbook.

UserForm2 requests the user to enter the test number for each test to be processed. The default test parameters are retrieved from the test sensitivity file and displayed on the form. The user may specify new values for any of the displayed test parameters. The test parameters include the subject id, weight, age, height and sitting height. Additional parameters include the cell type, nominal g level, subject type (manikin or human) and belt preload status (computed or not computed).

The workbook contains worksheets named "Channels", "Formulas", "Preloads", "Plots", "Time History File", "Plot Pages" and "Defaults". The "Channels" worksheet contains the channel number, channel name, database ID number, channel description, and summary sheet description for each channel. The "Formulas" worksheet contains Excel formulas and Excel functions. The "Preloads" worksheet contains the preload numbers and descriptions. The "Plots" worksheet contains the channel name, the plot description, and the plot vertical axis minimum, maximum and increment for each channel to be plotted. The "Time History File" worksheet defines the channel names for the time history files (the database time history files do not use this worksheet). The "Plot Pages" worksheet allows the user to print out selected plot pages (by default, all plot pages are printed).

WhutrBpr generates time histories for the piston z acceleration and displacement; the cable force; the head x, y, z, Ry and resultant accelerations; the chest x, y, z, Ry and resultant accelerations; the left, right and center headrest x forces and their sum; and the left, right and center upper seat back x forces and their sum. If the LOIS or ADAM manikin is used as the test subject, then time histories are also generated for the internal neck x, y, z and resultant forces; and the internal neck Mx, My, Mz and resultant torques.

The pre-impact values are subtracted from all of the external force time histories except the cable force. The HIC and the NIJ results are also calculated.

Values for the pre-impact level and the extrema for each time history are stored in the Excel worksheet summary file and printed out as a summary sheet for each test. The retraction time is calculated and printed out on the summary sheet. The time histories are also plotted with up to six plots per page. The user has the option to create test summary information and Excel workbooks containing the time histories for the Biodynamic Data Bank.

# Program Setup and Calibration Log

| | | |
|---|---|---|
| PROGRAM: UPPER TORSO RETRACTION WITH WEIGHTED HELMET STUDY (WHUTR) | TEST DATES: 18 June 2001 - 11 Sept 2002 | |
| STUDY NUMBER: 200101 | TEST NUMBERS: 1530 - 1937 | |
| FACILITY: BODY POSITIONING RESTRAINT DEVICE | SAMPLE RATE: | 1K |
| DATA COLLECTION SYSTEM: EME 24 CHANNEL | FILTER FREQUENCY: | 120 |
| | TRANDUCER RANGE (VOLTS): | +/-2.5 |

| DATA CHANNEL | DATA POINT | TRANSDUCER MFG. & | SERIAL NUMBER | PRE-CAL DATE | PRE-CAL SENS | POST-CAL DATE | POST-CAL SENS | % Δ | EXC. VOL. | AMP GAIN | FULL SCALE | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HEAD X ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R12 | 29-Aug-01 | 2.3076 mv/g | 16-Sep-02 | 2.2935 mv/g | -0.6 | 10 V | 10.8 | 100 G | USED FOR HUMAN TEST 1655 - 1937. |
| 1 | INT HEAD X ACCEL (G) | ENTRAN EGV3-F-250 | 97C97C27 TB06 | 22-May-01 | .9078 mv/g | 9-Aug-01 | .9035 mv/g | -0.5 | 10 V | 27.5 | 100 G | USED FOR LOIS TESTS 1530 - 1624. |
| 1 | INT HEAD X ACCEL (G) | ENTRAN EGA-125-100D | 93F93F11-P19 | 21-May-01 | 1.9612 mv/g | 25-Sep-01 | 1.9457 mv/g | -0.8 | 10 V | 12.7 | 100 G | USED FOR ADAM-L TEST. Test 1625 - 1654. |
| 2 | HEAD Y ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R13 | 29-Aug-01 | 2.3331 mv/g | 16-Sep-02 | 2.3373 mv/g | 0.2 | 10 V | 10.7 | 100 G | USED FOR HUMAN TEST 1655 - 1937. |
| 2 | INT HEAD Y ACCEL (G) | ENTRAN EGV3-F-250 | 97C97C27 TB06 | 22-May-01 | -.9488 mv/g | 9-Aug-01 | .9389 mv/g | -1 | 10 V | 26.3 | 100 G | USED FOR LOIS TEST 1530 - 1624. USE NEGATIVE SENSITIVITY. |
| 2 | INT HEAD Y ACCEL (G) | ENTRAN EGA-125-100D | 96E95C07-R04 | 21-May-01 | -1.6233 mv/g | 24-Sep-01 | 1.6346 mv/g | 0.7 | 10 V | 15.4 | 100 G | USED FOR ADAM-L TEST 1625 - 1654. USE NEGATIVE SENSITIVITY. |
| 3 | HEAD Z ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R14 | 29-Aug-01 | 2.2681 mv/g | 9/16/2002 | 2.3133 mv/g | 2 | 10 V | 11 | 100 G | USED FOR HUMAN TEST 1655 - 1937. |
| 3 | INT HEAD Z ACCEL (G) | ENTRAN EGV3-F-250 | 97C97C27 TB06 | 22-May-01 | .9078 mv/g | 09-Aug-01 | .9078 mv/g | 0 | 10 V | 27.5 | 100 G | USED FOR LOIS TEST 1530 - 1624. |
| 3 | INT HEAD Z ACCEL (G) | ENTRAN EGA-125-100D | 93F93F11-P13 | 21-May-01 | 1.9541 mv/g | 25-Sep-01 | 1.9414 mv/g | -0.6 | 10 V | 12.8 | 100 G | USED FOR ADAM-L TEST 1625 - 1654. |
| 4 | HEAD Ry ANG ACCEL (RAD/SEC2) | ENDEVCO 7302B | F93M | 29-Sep-01 | 4.71 uv/rad/sec2 | 16-Sep-02 | 4.61 uv/rad/sec2 | -2.1 | 10 V | 106.2 | 5000 RAD/SEC2 | USED FOR HUMAN TEST 1655 - 1937. |
| 4 | INT HEAD Ry ACCEL (RAD/SEC2) | ENDEVCO 7302BM2 | 10005 | 23-May-01 | -45.38 uv/rad/sec2 | 3-Aug-01 | 45.33 uv/rad/sec2 | -0.1 | 10 V | 11 | 5000 RAD/SEC2 | USED FOR LOIS TEST 1530 - 1624. USE NEGATIVE SENSITIVITY. |
| 4 | INT HEAD Ry ACCEL (RAD/SEC2) | ENDEVCO 7302BM2 | 10006 | 22-May-01 | 48.93 uv/rad/sec2 | 25-Sep-01 | 48.20 uv/rad/sec2 | -1.5 | 10 V | 10.2 | 5000 RAD/SEC2 | USED FOR ADAM-L TEST 1625 - 1654. |
| 5 | CHEST X ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R08 | 21-May-01 | 2.162 mv/g | 16-Sep-02 | 2.2002 mv/g | 1.8 | 10 V | 23.1 | 50 G | USED FOR HUMAN TEST 1655 - 1937. |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | INT CHEST X ACCEL (G) | ENTRAN EGV3-F-250 | 97F97F10 TP06 | 22-May-01 | .8908 mv/g | 9-Aug-01 | .8852 mv/g | -0.6 | 10 V | 56.1 | 50 G | USED FOR LOIS TEST 1530 - 1624. |
| 5 | INT CHEST X ACCEL (G) | ENTRAN EGA-125-100D | 93F93F11-P14 | 21-May-01 | 1.8212 mv/g | 25-Sep-01 | 1.8156 mv/g | -0.3 | 10 V | 27.5 | 50 G | USED FOR ADAM-L TEST 1625 - 1654. |
| 6 | CHEST Y ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R11 | 23-May-01 | 2.1592 mv/g | 16-Sep-02 | 2.162 mv/g | 0.1 | 10 V | 23.2 | 50 G | USED FOR HUMAN TEST 1655 - 1937. |
| 6 | INT CHEST Y ACCEL (G) | ENTRAN EGV3-F-250 | 97F97F10 TP06 | 22-May-01 | -.8837 mv/g | 9-Aug-01 | .8739 mv/g | -1.1 | 10 V | 56.6 | 50 G | USED FOR LOIS TEST 1530 - 1624.<br>USE NEGATIVE SENSITIVITY. |
| 6 | INT CHEST Y ACCEL (G) | ENTRAN EGA-125-100D | 93F93F11-P04 | 22-May-01 | -1.9131 mv/g | 25-Sep-01 | 1.8834 mv/g | -1.5 | 10 V | 26.1 | 50 G | USED FOR ADAM-L TEST 1625 - 1654.<br>USE NEGATIVE SENSITIVITY |
| 7 | CHEST Z ACCEL (G) | ENTRAN EGE-72-200 | 93C93C19-R10 | 21-May-01 | 2.1662 mv/g | 16-Sep-02 | 2.1747 mv/g | 0.4 | 10 V | 23.1 | 50 G | USED FOR HUMAN TEST 1655 - 1937. |
| 7 | INT CHEST Z ACCEL (G) | ENTRAN EGV3-F-250 | 97F97F10 TP06 | 22-May-01 | .9064 mv/g | 9-Aug-01 | .9035 mv/g | -2.2 | 10 V | 55.2 | 50 G | USED FOR LOIS TEST 1530 - 1624. |
| 7 | INT CHEST Z ACCEL (G) | ENTRA EGA-125-100D | 96F96F04-E06 | 21-May-01 | 1.6516 mv/g | 25-Sep-01 | 1.6388 mv/g | -0.8 | 10 V | 30.3 | 50 G | USED FOR ADAM-L TEST 1625 - 1654. |
| 8 | CHEST Ry ANG ACCEL (RAD/SEC2) | ENDEVC0 7302BM2 | 10024 | 29-Aug-01 | 45.29 uv/rad/sec2 | 16-Sep-02 | 44.5 uv/rad/sec2 | -1.7 | 10 V | 11 | 5000 RAD/SEC2 | USED FOR HUMAN TEST 1655 - 1937. |
| 8 | INT CHEST Ry ANG ACCEL (RAD/SEC2) | ENDEVCO 7302B | F96M | 22-May-01 | 3.39 uv/rad/sec2 | 3-Aug-01 | 3.38 uv/rad/sec | -0.3 | 10 V | 147.5 | 5000 RAD/SEC2 | USED FOR LOIS TEST 1530 - 1624. |
| 8 | INT CHEST Ry ANG ACCEL (RAD/SEC2) | ENDEVCO 7302B | F04G | 23-May-01 | 4.23 uv/rad/sec2 | 25-Sep-01 | 4.20 uv/rad/sec2 | -0.7 | 10 V | 118.2 | 5000 RAD/SEC2 | USED FOR ADAM-L TEST 1625 - 1654. |
| 9 | INT NECK X FORCE (LB) | DENTON 1716A | 718 | 1-Jun-01 | -8.00 uv/lb | 1-Aug-01 | 7.93 uv/lb | -0.9 | 10 V | 125 | 2500 LB | USED FOR LOIS TEST 1530 - 1624.<br>USE NEGATIVE SENSITIVITY. |
| 9 | INT NECK X FORCE (LB) | DENTON 1716A | 127 | 1-Jun-01 | 8.12 uv/lb | 27-Sep-01 | 8.12 uv/lb | 0 | 10 V | 123.2 | 2500 LB | USED FOR ADAM-L TEST 1625 - 1654. |
| 10 | INT NECK Y FORCE (LB) | DENTON 1716A | 718 | 1-Jun-01 | -8.31 uv/lb | 1-Aug-01 | 8.16 uv/lb | -1.8 | 10 V | 120.3 | 2500 LB | USED FOR LOIS TEST 1530 - 1624.<br>USE NEGATIVE SENSITIVITY. |
| 10 | INT NECK Y FORCE (LB) | DENTON 1716A | 127 | 1-Jun-01 | 8.41 uv/lb | 27-Sep-01 | 8.20 uv/lb | -2.5 | 10 V | 118.9 | 2500 LB | USED FOR ADAM-L TEST 1625 - 1654. |
| 11 | INT NECK Z FORCE (LB) | DENTON 1716A | 718 | 1-Jun-01 | -4.44 uv/lb | 08-Jan-01 | 4.43 uv/lb | -0.2 | 10 V | 225.2 | 2500 LB | USED FOR LOIS TEST 1530 - 1624.<br>USE NEGATIVE SENSITIVITY. |
| 11 | INT NECK Z FORCE (LB) | DENTON 1716A | 127 | 1-Jun-01 | 4.64 uv/lb | 27-Sep-01 | 4.65 uv/lb | 0.2 | 10 V | 215.5 | 2500 LB | USED FOR ADAM-L TEST Test 1625 - 1654. |

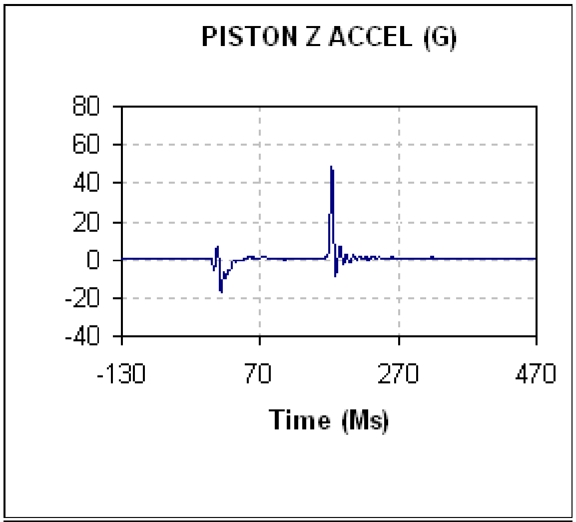
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | INT NECK My TORQUE (IN-LB) | DENTON 1716A | 718 | 1-Jun-01 | 6.74 uv/in-lb | 01-Aug-01 | 6.73 uv/in-lb | -0.1 | 10 V | 148.4 | 2500 IN-LB | USED FOR LOIS TEST 1530 - 1624. |
| 13 | INT NECK My TORQUE (IN-LB) | DENTON 1716A | 127 | 1-Jun-01 | 6.88 uv/in-lb | 27-Sep-01 | 6.89 uv/in-lb | 0.1 | 10 V | 145.3 | 2500 IN-LB | USED FOR ADAM-L TEST 1625 - 1654. |
| 14 | INT NECK Mz TORQUE (IN-LB) | DENTON 1716A | 718 | 1-Jun-01 | 9.12 uv/in-lb | 01-Aug-01 | 9.10 uv/in-lb | -0.2 | 10 V | 109.6 | 2500 IN-LB | USED FOR LOIS TEST 1530 - 1624. |
| 14 | INT NECK Mz TORQUE (IN-LB) | DENTON 1716A | 127 | 1-Jun-01 | 9.26 uv/in-lb | 27-Sep-01 | 9.21 uv/in-lb | -0.5 | 10 V | 108 | 2500 IN-LB | USED FOR ADAM-L TEST 1625 - 1654. |
| 15 | PISTON Z DISPLACEMENT (IN) | ANALOG INPUT | NA | NA | 100 mv/in | | | | 10 V | 1.7 | 15 IN | USED FOR ALL TEST |
| 16 | INT NECK Mx TORQUE (IN-LB) | DENTON 1716A | 718 | 1-Jun-01 | 6.68 uv/in-lb | 01-Aug-01 | 6.70 uv/in-lb | 0.3 | 10 V | 149.7 | 2500 IN-LB | USED FOR LOIS TEST 1530 - 1624. |
| 16 | INT NECK Mx TORQUE (IN-LB) | DENTON 1716A | 127 | 1-Jun-01 | 6.82 uv/in-lb | 27-Sep-01 | 6.86 uv/in-lb | 0.6 | 10 V | 146.6 | 2500 IN-LB | USED FOR ADAM-L TEST 1625 - 1654. |
| 17 | CABLE FORCE (LB) | STRAINSERT FL2.5U-2SPKT | Q-3294-2 | 9-Feb-01 | 8.11 uv/lb | 16-Sep-02 | 8.27 uv/lb | 2 | 10 V | 123.3 | 2500 LB | USED FOR ALL TEST |
| 18 | PISTON Z ACCEL (G) | ENDEVCO 7264-200 | CM18H | 20-Mar-01 | 3.2013 mv/g | 16-Sep-02 | 3.2451 mv/g | 1.4 | 10 V | 7.8 | 100 G | USED FOR ALL TEST |
| 19 | LEFT UPPER SEAT BACK X FORCE (LB) | STRAINSERT FL2.5U-2SGKT | Q-7588-3 | 21-Jul-00 | -7.85 uv/lb | 16-Sep-02 | 7.82 uv/lb | -0.3 | 10 V | 127.4 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| 20 | RIGHT UPPER SEAT BACK X FORCE (LB) | STRAINSERT FL2.5U-2SGKT | Q-7588-2 | 21-Jul-00 | -7.98 uv/lb | 16-Sep-02 | 7.91 uv/lb | -0.9 | 10 V | 125.3 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| 21 | CENTER UPPER SEAT BACK X FORCE (LB) | STRAINSERT FL2.5U-2SGKT | Q-7588-1 | 21-Jul-00 | -7.79 uv/lb | 16-Sep-02 | 7.84 uv/lb | 0.6 | 10 V | 128.4 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| 22 | LEFT HEADREST X FORCE (LB) | STRAINSERT FLU2.5-2SPKT | Q-7135-2 | 20-Jul-00 | -7.95 uv/lb | 16-Sep-02 | 7.82 uv/lb | -1.6 | 10 V | 125.8 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| 23 | RIGHT HEADREST X FORCE (LB) | STRAINSERT FL2.5U-2SPKT | Q-7135-1 | 21-Jul-00 | -7.96 uv/lb | 16-Sep-02 | 7.94 uv/lb | -0.3 | 10 V | 125.6 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| 24 | CENTER HEADREST X FORCE (LB) | STRAINSERT FL2.5U-2SPKT | Q-7135-3 | 21-Jul-00 | -7.77 uv/lb | 16-Sep-02 | 7.92 uv/lb | 1.9 | 10 V | 128.7 | 2500 LB | USED FOR ALL TEST. USE NEGATIVE SENSITIVITY. |
| D-1 | T0 PULSE (VOLTS) | | | | 1 V | | | | | | | DIGITAL INPUT CHANNEL 4 |
| D-2 | REFERENCE MARK TIME (VOLTS) | | | | 1 V | | | | | | | DIGITAL INPUT CHANNEL 3 |

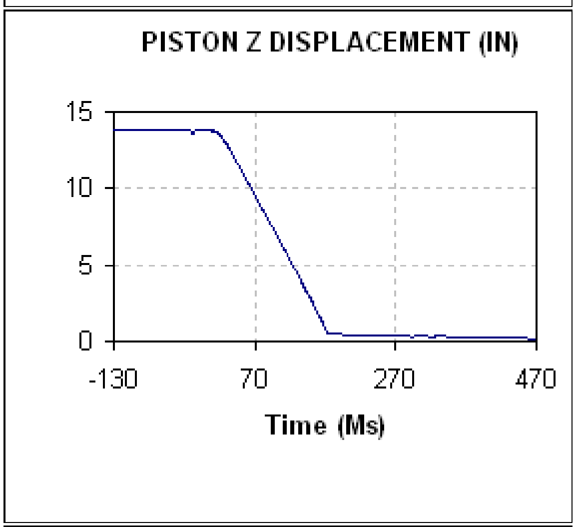
# APPENDIX B – SAMPLE ACCELERATION/FORCE DATA

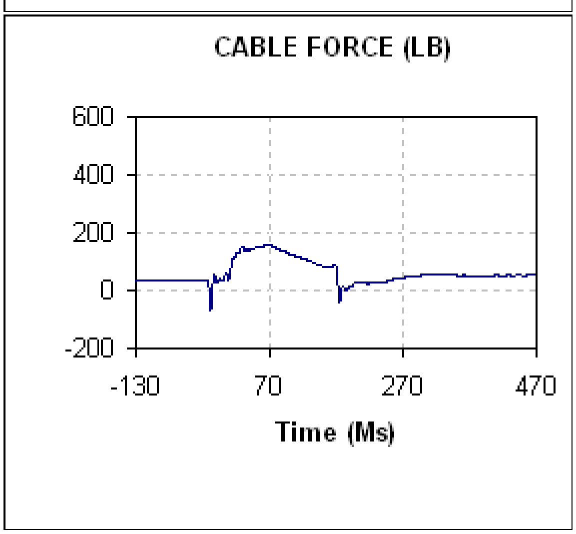
WHUTR Study  Test: 1830  Test Date: 020702  Subj: B-32  Wt: 116.0
Nom G: .0  Cell: SS

| Data ID | Immediate Preimpact | Maximum Value | Minimum Value | Time Of Maximum | Time Of Minimum |
|---|---|---|---|---|---|
| Reference Mark Time (Ms) | | | | -135.0 | |
| Impact Rise Time (Ms) | | | | 13.0 | |
| Impact Duration (Ms) | | | | 52.0 | |
| Velocity Change (Ft/Sec) | | 5.48 | | | |
| Haulback Time (Ms) | | | | 178.0 | |
| | | | | | |
| Piston Z Acceleration (G) | 0.94 | 48.86 | -17.48 | 174.0 | 13.0 |
| Piston Z Displacement (In) | 13.78 | 13.81 | 0.16 | 0.0 | 470.0 |
| | | | | | |
| Head Acceleration (G) | | | | | |
| X Axis | 0.00 | 4.56 | -6.51 | 204.0 | 68.0 |
| Y Axis | 0.00 | 1.12 | -0.64 | 197.0 | 72.0 |
| Z Axis | 0.98 | 7.95 | -5.45 | 195.0 | 67.0 |
| Resultant | 0.98 | 8.64 | 0.07 | 198.0 | 252.0 |
| Ry (Rad/Sec2) | -0.64 | 634.34 | -639.56 | 70.0 | 128.0 |
| HIC | | 3.00 | | 191.0 | 206.0 |
| | | | | | |
| Chest Acceleration (G) | | | | | |
| X Axis | 0.01 | 5.35 | -6.33 | 44.0 | 201.0 |
| Y Axis | -0.01 | 1.56 | -1.06 | 179.0 | 39.0 |
| Z Axis | 1.00 | 7.07 | -10.05 | 22.0 | 179.0 |
| Resultant | 1.00 | 10.69 | 0.39 | 178.0 | 116.0 |
| Ry (Rad/Sec2) | -0.03 | 1008.63 | -939.34 | 185.0 | 29.0 |
| | | | | | |
| Cable Force (Lb) | 20.77 | 158.58 | -40.41 | 67.0 | 175.0 |
| | | | | | |
| Headrest X Force (Lb) | | | | | |
| Left | 0.00 | 0.09 | -3.57 | 27.0 | 5.0 |
| Right | 0.00 | 2.68 | -4.65 | 186.0 | 193.0 |
| Center | 0.00 | 1.17 | -2.49 | 195.0 | 68.0 |
| X Axis Sum | 0.00 | -0.94 | -8.26 | 188.0 | 178.0 |
| | | | | | |
| Seat Back X Force (Lb) | | | | | |
| Left Upper | 0.00 | 24.46 | -4.84 | 180.0 | 36.0 |
| Right Upper | 0.00 | 15.73 | -9.91 | 184.0 | 166.0 |
| Center Upper | 0.00 | 252.91 | -3.38 | 174.0 | 26.0 |
| Upper Sum | 0.00 | 278.45 | -10.80 | 178.0 | 26.0 |

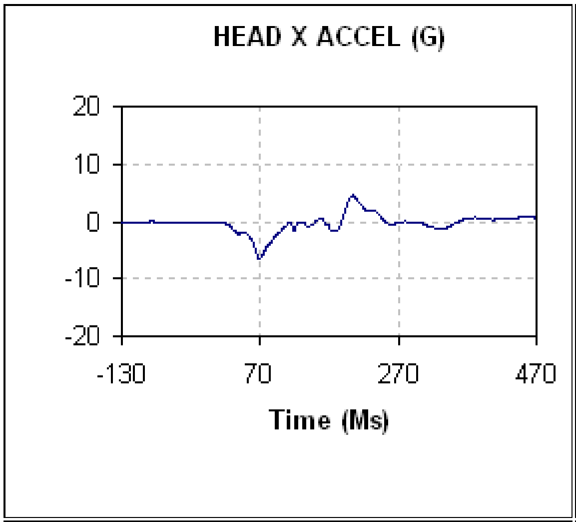
WHUTR Study  Test: 1830  Test Date: 020702  Subj: B-32  Cell: SS

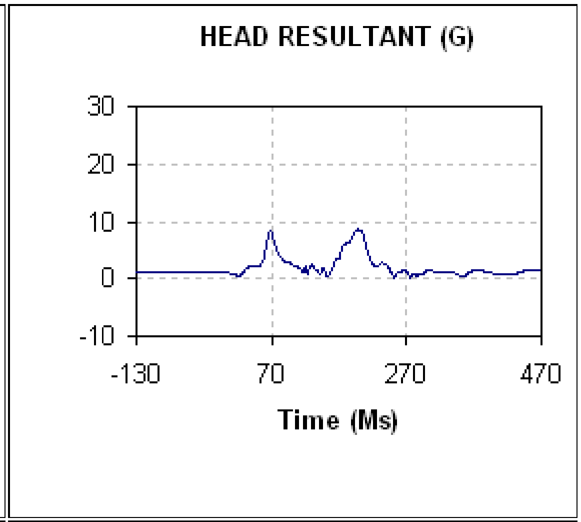


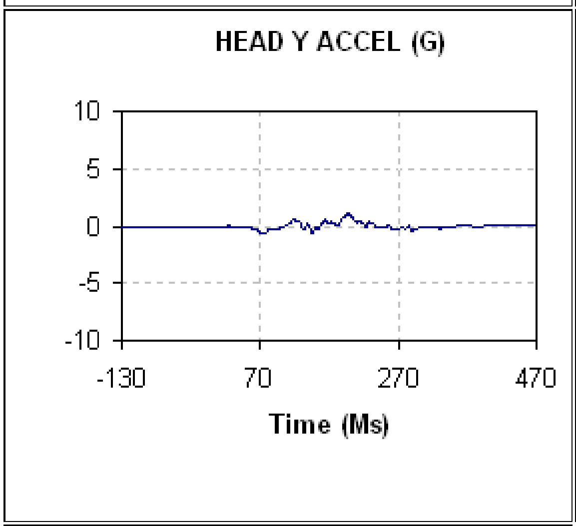



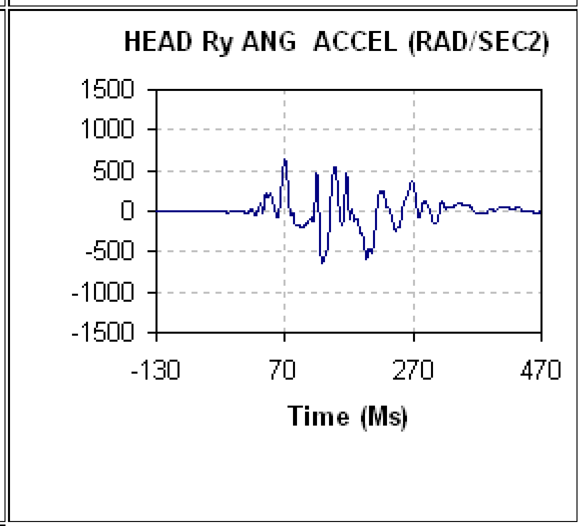



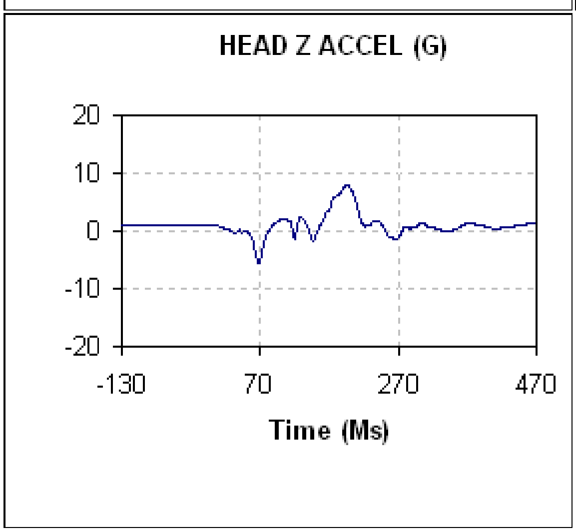
WHUTR Study  Test: 1830  Test Date: 020702  Subj: B-32  Cell: SS



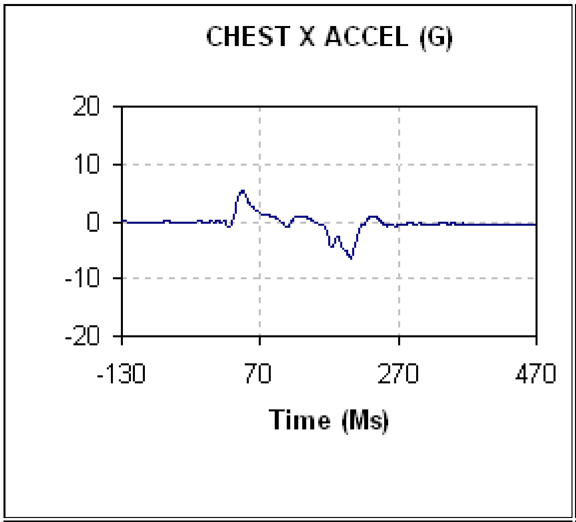



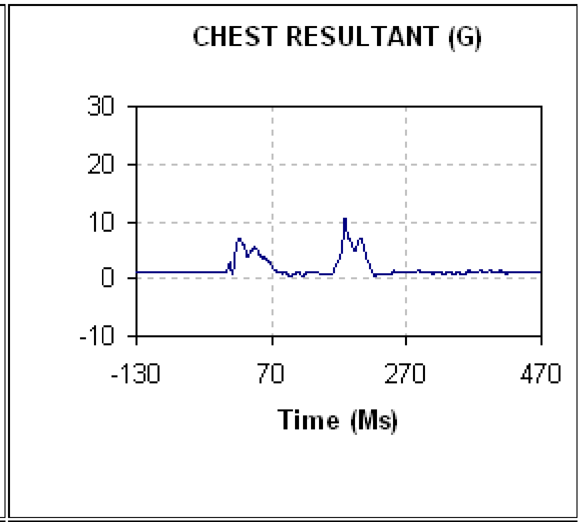



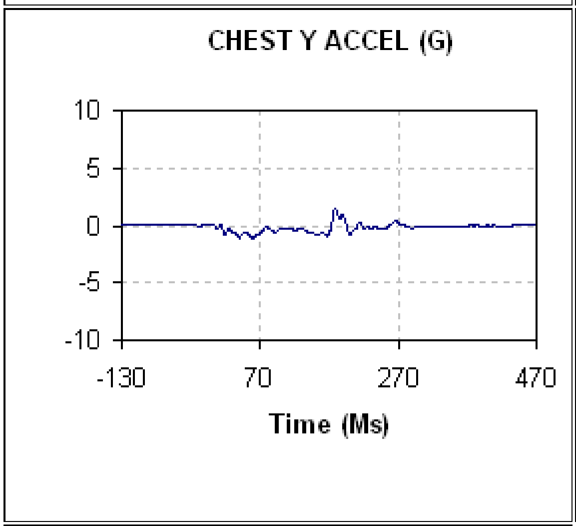



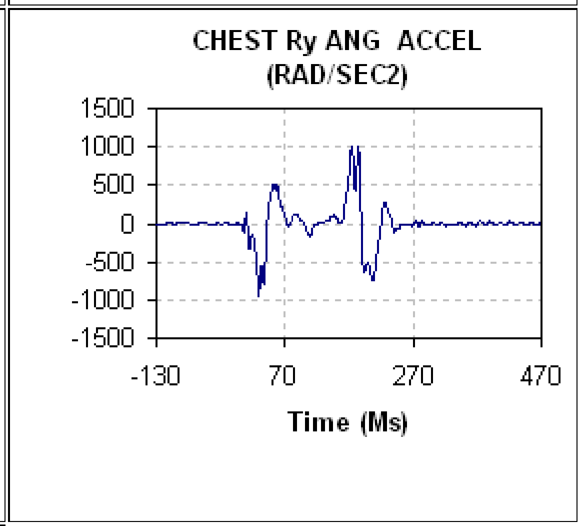



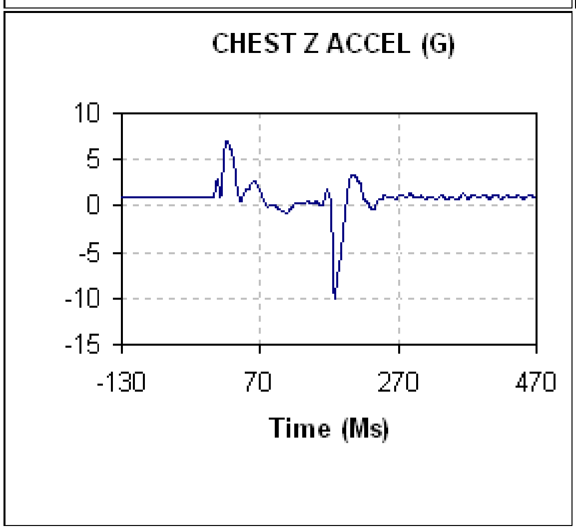
WHUTR Study Test: 1830 Test Date: 020702 Subj: B-32 Cell: SS



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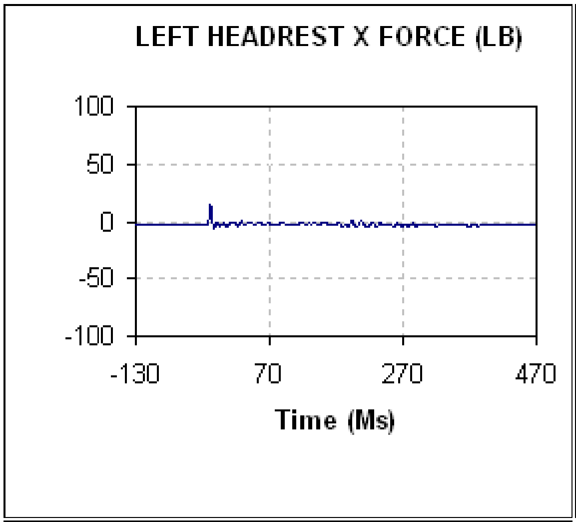
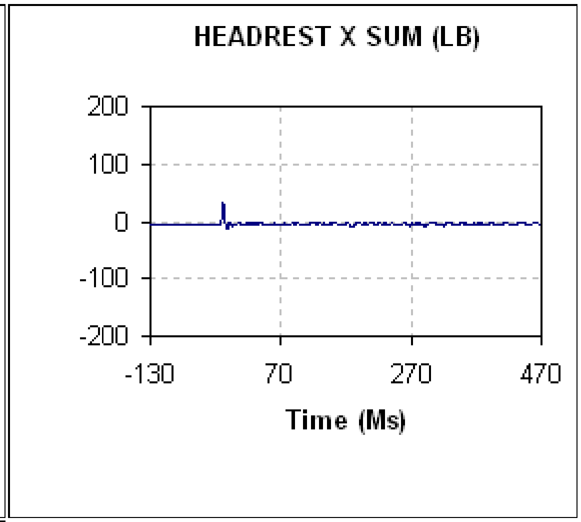
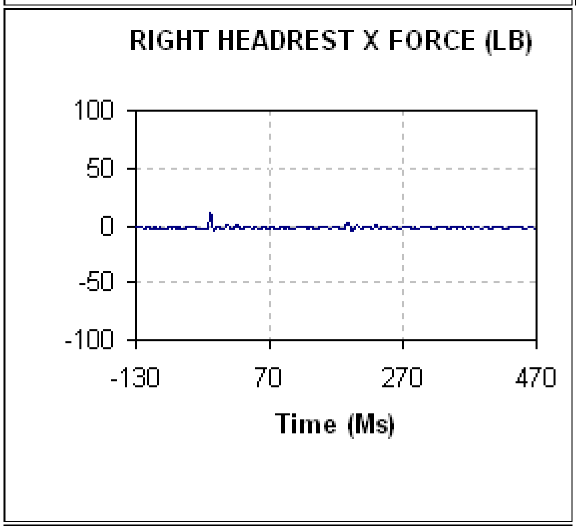
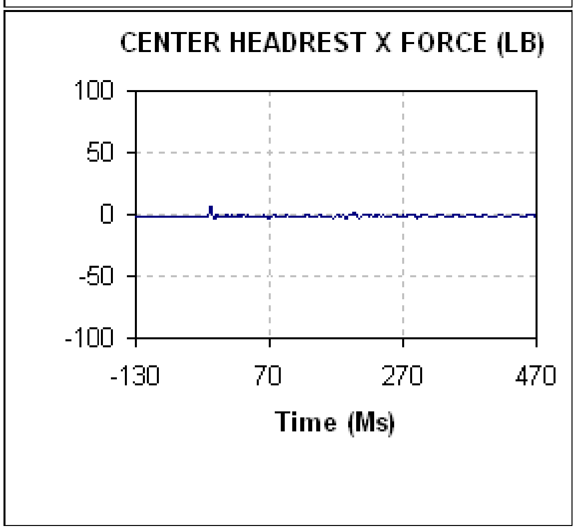
WHUTR Study  Test: 1830  Test Date: 020702  Subj: B-32  Cell: SS

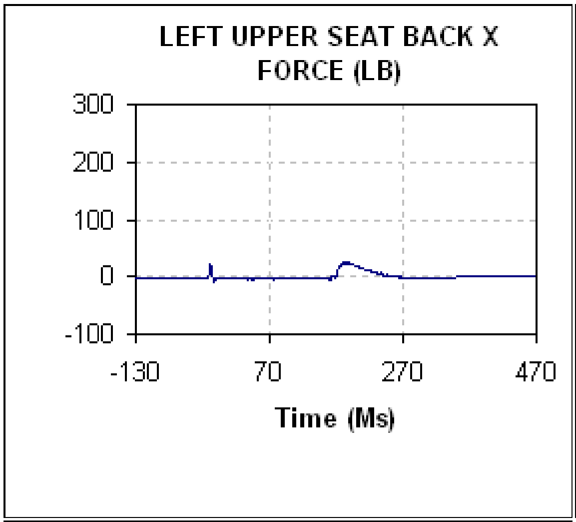


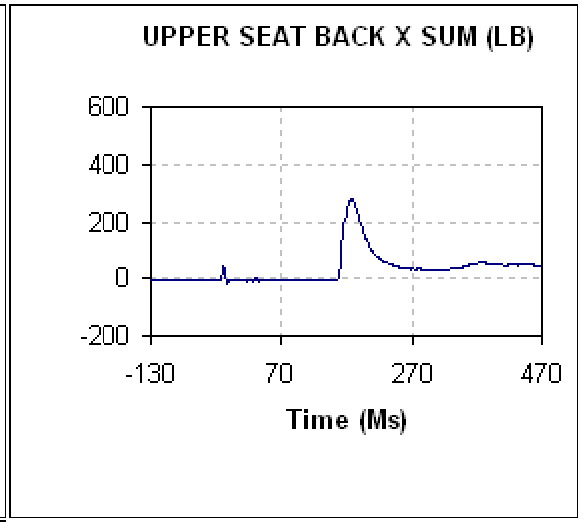



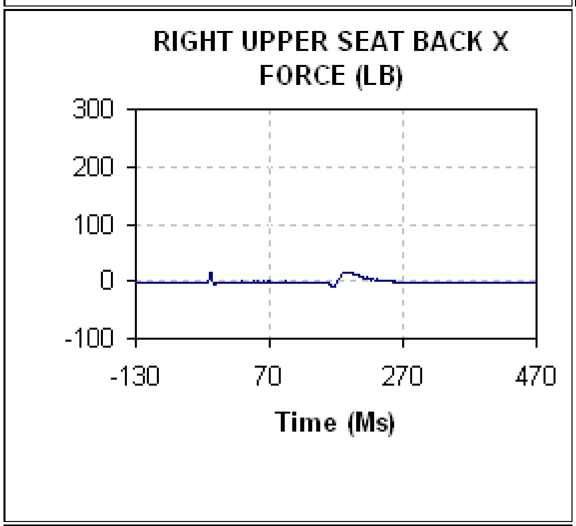



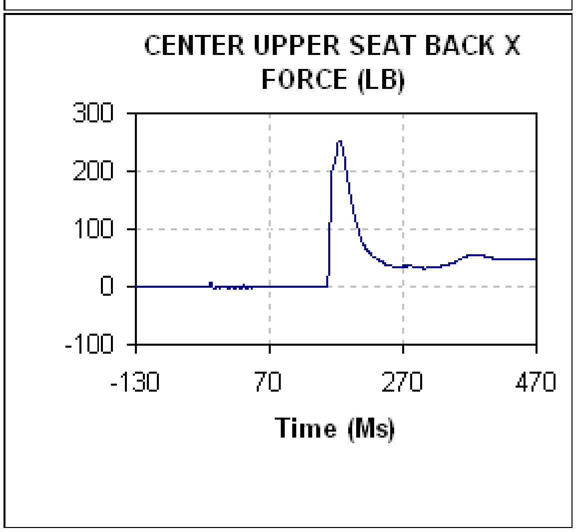



WHUTR Study  Test: 1830  Test Date: 020702  Subj: B-32  Cell: SS



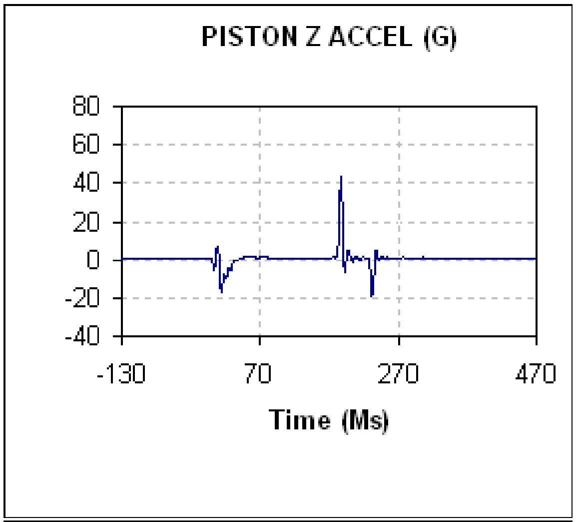



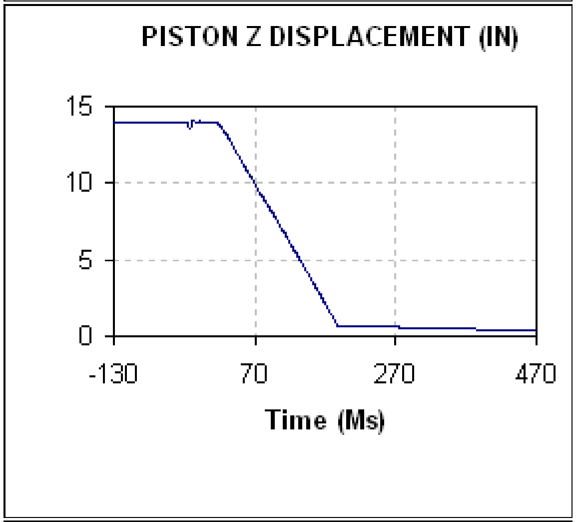



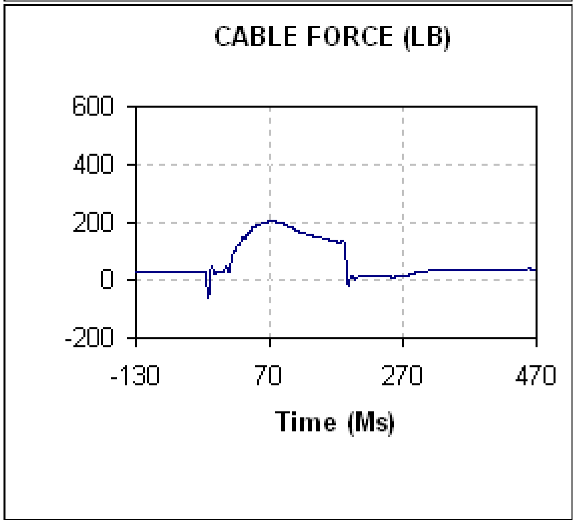
WHUTR Study  Test: 1920  Test Date: 020909  Subj: M-34  Wt: 266.0
Nom G: .0  Cell: SS

| Data ID | Immediate Preimpact | Maximum Value | Minimum Value | Time Of Maximum | Time Of Minimum |
|---|---|---|---|---|---|
| Reference Mark Time (Ms) | | | | -138.0 | |
| Impact Rise Time (Ms) | | | | 232.0 | |
| Impact Duration (Ms) | | | | 236.0 | |
| Velocity Change (Ft/Sec) | | 4.77 | | | |
| Haulback Time (Ms) | | | | 217.0 | |
| | | | | | |
| Piston Z Acceleration (G) | 0.98 | 43.82 | -18.99 | 187.0 | 232.0 |
| Piston Z Displacement (In) | 13.94 | 14.01 | 0.36 | 0.0 | 463.0 |
| | | | | | |
| Head Acceleration (G) | | | | | |
| X Axis | 0.03 | 2.10 | -4.17 | 229.0 | 89.0 |
| Y Axis | 0.00 | 1.03 | -0.68 | 135.0 | 252.0 |
| Z Axis | 0.97 | 4.45 | -2.70 | 203.0 | 88.0 |
| Resultant | 0.97 | 4.96 | 0.25 | 89.0 | 351.0 |
| Ry (Rad/Sec2) | -3.02 | 323.53 | -345.15 | 93.0 | 134.0 |
| HIC | | 0.69 | | 81.0 | 96.0 |
| | | | | | |
| Chest Acceleration (G) | | | | | |
| X Axis | 0.02 | 4.01 | -5.33 | 127.0 | 221.0 |
| Y Axis | -0.01 | 0.88 | -1.87 | 198.0 | 233.0 |
| Z Axis | 0.99 | 7.29 | -9.32 | 39.0 | 213.0 |
| Resultant | 0.99 | 9.91 | 0.18 | 213.0 | 174.0 |
| Ry (Rad/Sec2) | -0.38 | 2883.98 | -1727.44 | 213.0 | 50.0 |
| | | | | | |
| Cable Force (Lb) | 15.04 | 204.96 | -23.32 | 72.0 | 188.0 |
| | | | | | |
| Headrest X Force (Lb) | | | | | |
| Left | 0.00 | 2.86 | -6.90 | 203.0 | 211.0 |
| Right | 0.00 | 4.51 | -5.26 | 197.0 | 190.0 |
| Center | 0.00 | 1.03 | -5.07 | 197.0 | 188.0 |
| X Axis Sum | 0.00 | 1.08 | -12.35 | 198.0 | 191.0 |
| | | | | | |
| Seat Back X Force (Lb) | | | | | |
| Left Upper | 0.00 | 65.44 | -2.91 | 218.0 | 6.0 |
| Right Upper | 0.00 | 62.12 | -3.80 | 217.0 | 25.0 |
| Center Upper | 0.00 | 160.91 | -3.85 | 195.0 | 18.0 |
| Upper Sum | 0.00 | 277.49 | -8.12 | 217.0 | 25.0 |

WHUTR Study  Test: 1920  Test Date: 020909  Subj: M-34  Cell: SS



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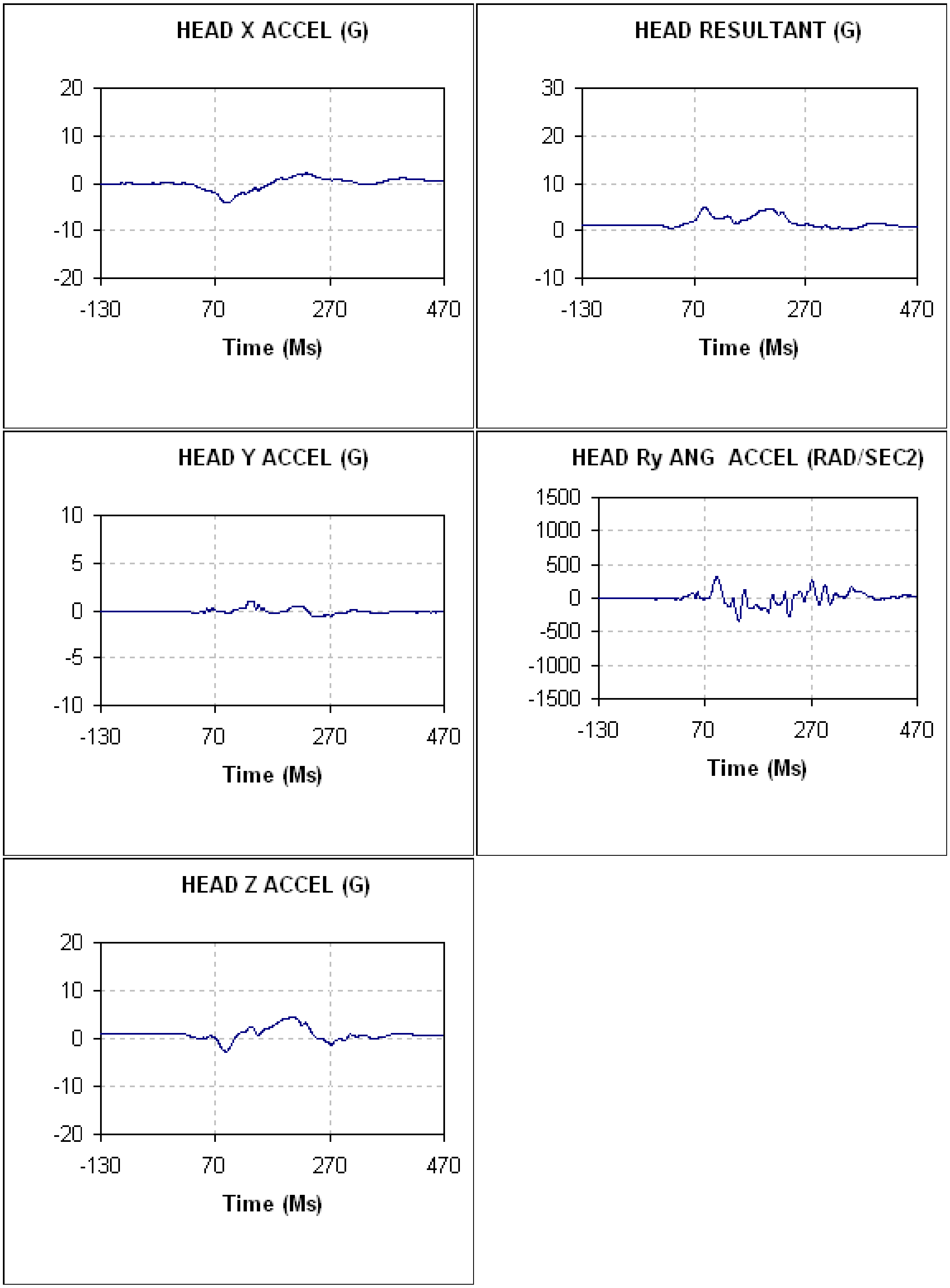

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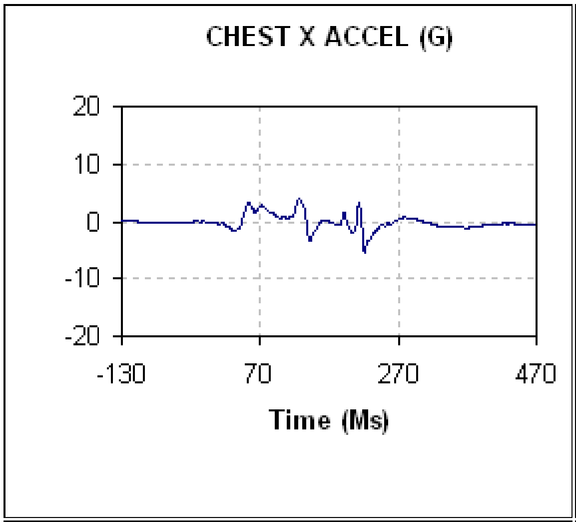


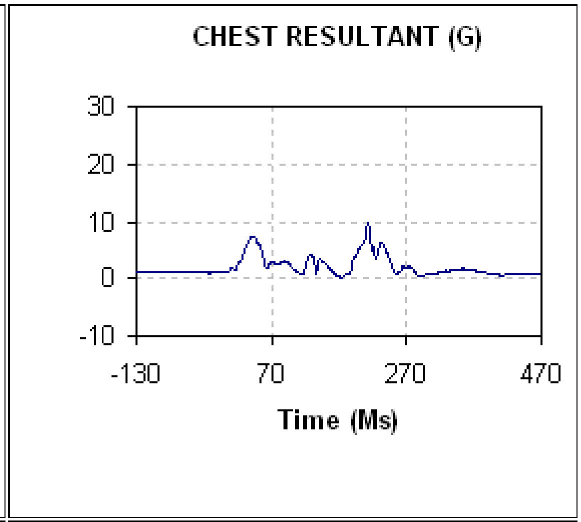


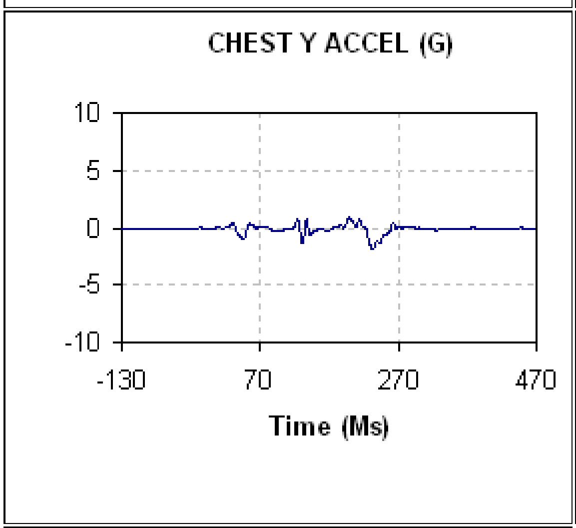


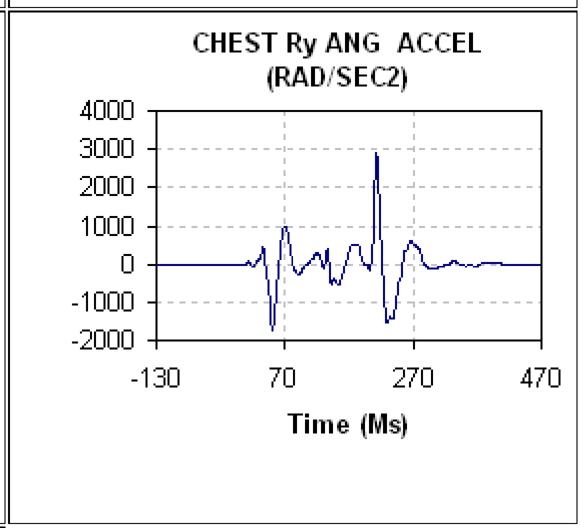


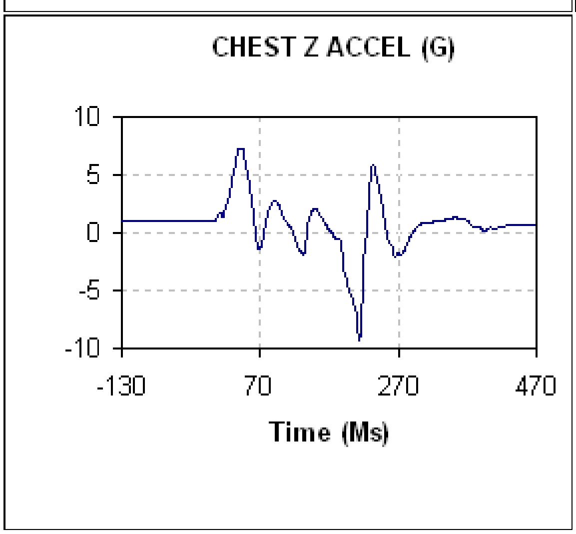

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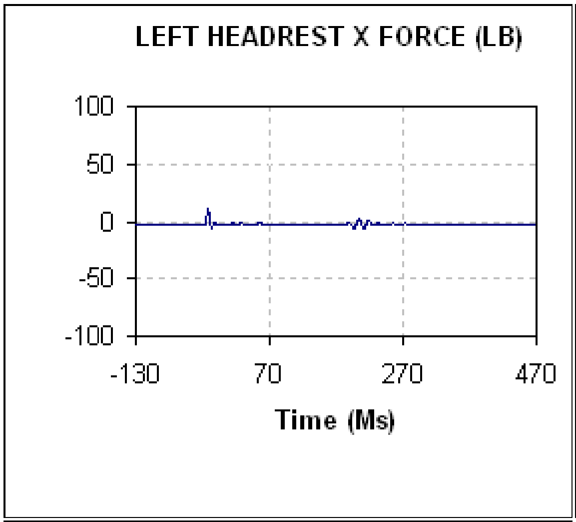


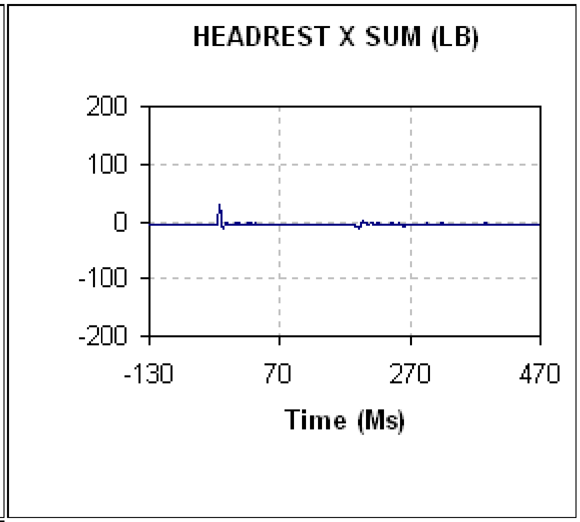


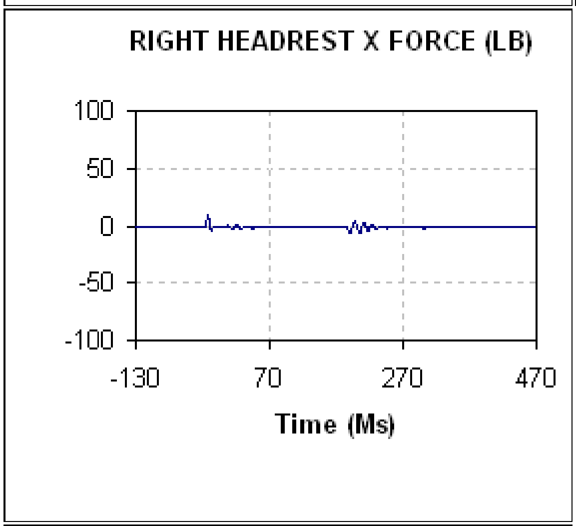


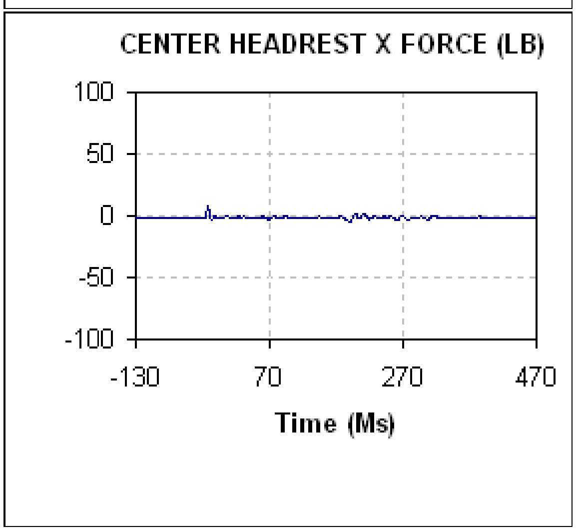

WHUTR Study  Test: 1920  Test Date: 020909  Subj: M-34  Cell: SS